Power and Environmental System Assessment for the Black Island Telecommunications Facility

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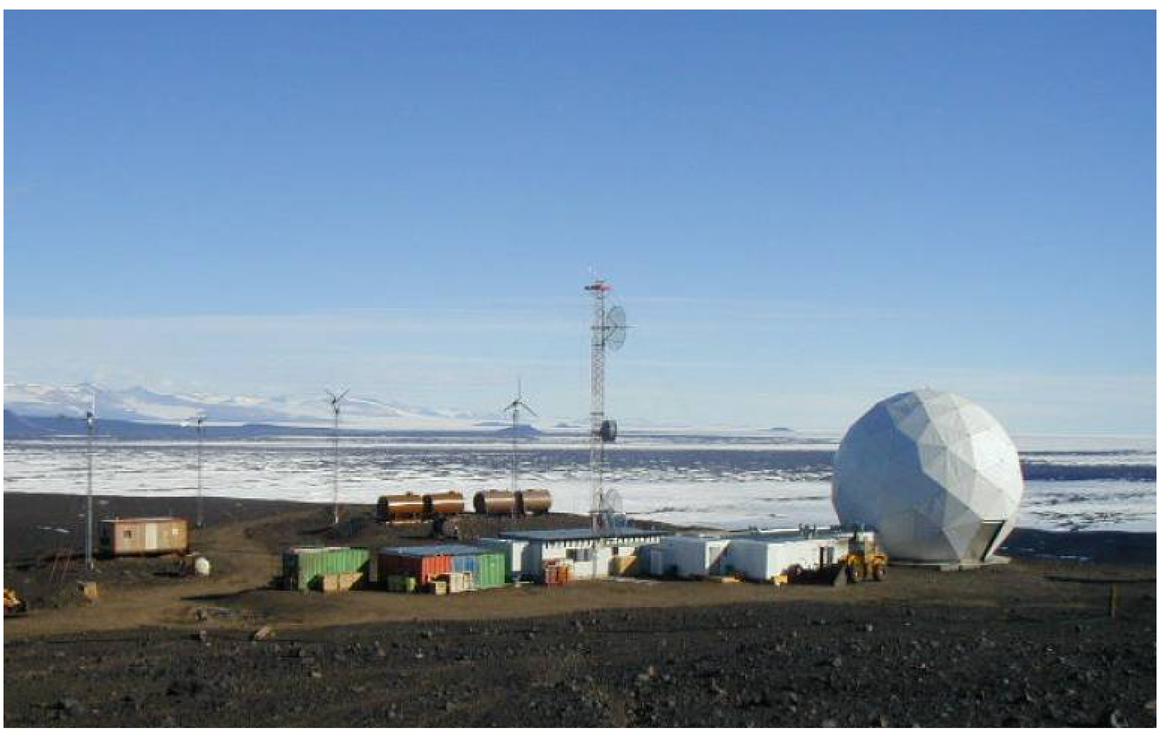

Executive Summary

The Black Island Telecommunications Facility (BITF) is a critical communications facility for the National Science Foundation's (NSF) McMurdo base operations. The BITF consists of an active 11-meter and a spare 7.2-meter satellite antenna for the data link via microwave antenna to McMurdo Station, HF antennas for local and regional communications, and the facilities necessary to power and sustain these communication systems. To operate these antennas and the supporting infrastructure, all power is generated on site. The hybrid power system, supplied by Northern Power Systems (NPS), includes solar panels, wind turbines, diesel generators, batteries, and inverters.

The BITF power system was installed in the early 1990s and is approximately 13 years old, so it is important to evaluate the condition of this system to preempt any age related equipment failure and to specify a path for future upgrades and/or replacements so that the system can meet Raytheon Polar Services Company's (RPSC's) future needs at the BITF. To meet this need, RPSC asked the National Renewable Energy Laboratory (NREL) to perform an independent assessment of the BITF hybrid power system and heating and cooling system.

Several different upgrades, including a new system, are discussed in this report. Three different alternatives are evaluated and include: 1) minor upgrades to the system; 2) significant changes to the system; and 3) a complete new system. The alternatives presented encompass a wide range of modifications that could be made to the facility and were chosen as three logical "scenarios" that reflect a gradual change from simple and less expensive to more complex and more expensive. The three scenarios were chosen as a logical way to group the different modifications.

A final decision on modifying the BITF power and environmental system will be influenced by factors not known at this time, including available funding, future changes to the communication system at Black Island (BI), and potential future operational changes at McMurdo station.

Major changes that should be considered for the BITF power and environmental system include: new inverters, new diesels, high efficiency boiler, maximum peak power tracker, a "hot swappable" programmable logic controller (PLC), changing from a 24-volt to a 48-volt DC bus, and installation of one modified 1.8 kW STORM turbine manufactured by Southwest Windpower.

The new inverters would supply AC power directly to AC loads and control the flow of both AC and DC power on an upgraded 48-volt DC bus. State-of-the-art inverters are capable of supplying AC power directly to an AC power bus from an AC source, such as a diesel generator, to meet AC loads and simultaneously rectify AC power to DC power to meet charging requirements of batteries and DC load requirements. A 48-volt DC bus typically is used to reduce wire size and directly meet 48-volt DC communication loads.

The Yanmar diesels are rated for 10,000 hours of use each, but with the good maintenance provided at BI have been able to go much longer. Two of the three diesels have exceeded this value by at least 50% and should be replaced soon.

A new high efficiency boiler is used to supply space heat instead of the existing AC glycol heaters. This increases the efficiency of the system dramatically because AC electricity is no longer used to generate heat, although this system can be kept in place and used as a backup should the boiler system fail for any reason. It should be noted that this marked increase in heating efficiency should be compared to the current heating efficiency that is limited to around 60%. Control of the heater is by the PLC, which will need to be re-programmed.

A maximum peak power tracker (MPPT) would increase the output of the photovoltaic (PV) panels by approximately 25%–30%. All PV modules have a maximum power point where the module voltage times the module current equals the maximum power. However, a PV system's maximum power point continually changes based on temperature and insolation. The MPPT controller tracks the maximum peak power and changes the voltage that the PV panel sees to the corresponding peak power voltage.

A hot swappable PLC would provide redundancy to the existing PLC should the PLC fail for any reason. Should a failure occur with the existing PLC, the failure would bring the entire system down. A redundant PLC would take away the risk of a single-point failure within the PLC that increases with the age of the system.

The loads are divided into the same three priority loads, except they are 48-volt DC or 120-volt AC loads. Some loads may have to remain 24-volts DC (e.g., the motor for the antenna) and will require a step-down transformer. Lighting is changed out to high efficiency 48-volt lighting and proximity sensors are put on all lights. Dampers and fans are also changed out to either 120-volt or 48-volt systems.

An extensive investigation into commercial wind turbines that could be used at BI produced only one potential candidate: the 1.8 kW STORM turbine manufactured by SouthwestWindpower (SWWP). Wind turbines that furl horizontally and cannot have their furl tension set would not hold up to the strong winds at BI. The STORM turbine does not furl in high winds. It uses stall control and solid-state control to load the alternator to limit rotor speeds in high winds.

As with the HR3 turbines originally installed with the system, the installation of the STORM turbine at BI would have to be considered a BETA test of the turbine, because the turbine cannot be tested anywhere else at the wind speeds found at BI. To install a STORM turbine at BI would require some minor cold weather modifications, such as changing bearing grease specifications for colder temperatures. Shortening the STORM blades does not reduce the loads significantly because the turbine is in a parked state in high winds.

It is recommended that one STORM turbine be installed to test the turbine at BI and to evaluate its performance. A review of the turbine's performance at BI could lead to its use for future polar applications in addition to BI. Extensive modeling using state-of-the-art computer code to predict wind turbine loads for the STORM turbine at the higher wind speeds at Black Island is contained in Appendix E.

Lastly, considerations for future energy upgrades in Antarctica are examined. The organizational and regulatory constraints are discussed in regards to project development in Antarctica including renewable energy and energy efficiency improvements at Marble Point, the application of small scale renewable energy to remote camps, and broader energy issues at McMurdo base. Large scale wind energy and issues related to energy efficiency, ranging from building thermal loads to the efficiency of the reverse osmosis system, are discussed.

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4.0 Background

The Black Island Telecommunications Facility (BITF) is a critical communications facility for the National Science Foundation's (NSF) McMurdo base operations. Black Island is located approximately 22 miles from McMurdo and is accessible by helicopter in the summer and via ground traverse in the winter. All resources for the BITF, including all support and logistics items, are supplied from McMurdo.

The BITF consists of an active 11-meter and spare 7.2-meter satellite antenna for the data link via microwave antenna to McMurdo Station, HF antennas for local and regional communications, and the facilities necessary to power and sustain these communications systems. To operate these antennas and the supporting infrastructure, all power is generated on site. The hybrid power system, supplied by Northern Power Systems (NPS), includes solar panels, wind turbines, diesel generators, batteries, and inverters. The environmental control system was designed and built by Raytheon Polar Services Company (RPSC) and its subcontractors. The power and environmental systems are both controlled by a Programmable Logic Controller (PLC) supplied by NPS. The PLC monitors the power and environmental systems to ensure that the BITF remains operational. Future plans for the BITF include significant upgrades to the telecommunications system as part of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) project.

The BITF power system was installed in the early 1990s and is approximately 13 years old, so it is important to evaluate the condition of this system to preempt any age related equipment failure and to specify a path for future upgrades and/or replacements so that the system can meet RPSC's future needs at the BITF. Therefore, RPSC asked the National Renewable Energy Laboratory (NREL) to perform an independent assessment of the BITF hybrid power system and heating and cooling system.

This report is based on the field observations made by Dave Corbus and Charles Newcomb of NREL during a site visit to the BITF from January 10 mid afternoon to the morning of January 11, 2006. Inclement weather and scheduling conflicts for helicopter time spurred by a U.S. Congressional contingent visiting Antarctica ultimately determined the time available for NREL to conduct the on-site assessment of the BITF facility. This report is also based on numerous conversations that occurred during the days before and after the site visit with various RPSC personnel at McMurdo Station that are directly and indirectly responsible for various operations and logistics affecting the BITF and that were historically involved with the system design, implementation, and early operation.

5.0 Evaluation of the Existing Power and Heating and Ventilation System

5.1 Overview

The BITF hybrid power system was installed in the early 90s as a high-reliability, state-of-the-art system. The most important design criterion of a high-reliability hybrid power system is to meet the electrical demands of all critical loads at all times. Because the system is unmanned during part of the year, in the event of any system or component failure, the system must be capable of annunciating system status faults and system states via remote communication to McMurdo

Station. The unit cost of energy for a high-reliability hybrid power system usually has less priority than the system reliability.

The BITF hybrid power system was designed in the early 1990s with state-of-the-art wind turbines, photovoltaic (PV) panels, inverters, and batteries. The hybrid power system's PLC was one of the most sophisticated of all hybrid power systems at the time. Since its installation, the PLC code has been refined and modified to keep pace with system changes and improvements.

This section presents an assessment of the existing hybrid power system and heating and ventilation system. The assessment forms the baseline characterization of the system from which modifications and improvements for the hybrid power system are discussed in the next section of this report. A simplified 1-line electrical schematic for the power system is shown in Appendix A.

5.2 Wind Generators

The existing wind generators are North Wind HR3 wind turbines manufactured by Northern Power Systems. The HR3 turbine was originally designed under a Department of Energy (DOE) contract for a high-reliability wind turbine. The turbines are rated at 3 kW at 12.5 m/s (28 mph). Important manufacturer specifications for the turbine are shown in Table 1, and the manufacturer's power curve is shown in Figure 1. NPS no longer manufacturers HR3 turbines and does not provide technical support or supply parts for the turbines installed.

At the time of its manufacture, the HR3 turbine was the most durable small wind turbine available and also the most expensive on a dollar per installed Watt basis. No other small turbine has demonstrated long operation in the extreme wind speeds characteristic of those observed at the BITF. Because no test facilities exist that offer wind speeds as high as those at the BITF, the BITF has been a unique test site for demonstrating small wind turbine survival in high wind speeds.

Table 1. North Wind HR 3 - Important Manufacturer's Technical Data

Rated power output	3000 watts @ 12.5 m/s (28 mph)
Peak power output	3200 watts @ 4.5 m/s (32.5 mph)
Cut-in wind speed	3.6 m/s (8 mph)
Design life	25 years
Rotor configuration	Horizontal axis, upwind, 3-bladed
Rotor diameter	5 m (16.4 ft)
Rotor speed control	Variable axis rotor control
Voltage (nominal)	24, 48, 110 VDC
Generator type	3-phase synchronous alternator
Field configuration	Lundel, shunt connected
Voltage regulation	Solid-state pulse width modulation (PWM) field control
Rectification	Silicon diode
Blade material	Wood laminate
Maximum survival wind speed (steady)	54 m/s (120 mph)
Maximum survival wind speed (gust)	74 m/s (165 mph)

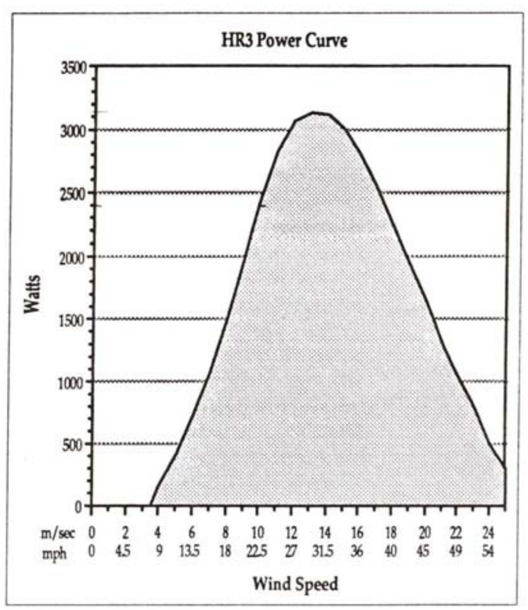

Figure 1. Manufacturer's Power Curve for the HR3

The HR3 wind turbine utilizes a Lundel alternator to generate variable-voltage AC current. This generator type offers field current control as part of the wind turbine battery charge controller. Turbine AC current is rectified and delivered as 24-volt DC to the 24-volt DC bus. Current is reduced to prevent over-charging the battery when the voltage on the DC bus reaches the high voltage set-point of the wind turbine charge controller. The turbine can also be connected to a resistive load to provide space heating if certain conditions, as controlled by the PLC, are met.

Rotor over-speed control, which is of critical importance at this high wind speed site, is provided by vertical furling of the turbine. This furling is affected by passively tilting the rotor/generator assembly back and out of the wind as wind speed, and thus rotor thrust, increase beyond a specific level. Without rotor over-speed control, the turbine would ultimately self destruct at high wind speeds. Rotor tilt reactive force is provided via a field adjustable torsion spring.

Many other small turbines also use furling for over-speed protection, and this furling behavior has been modeled and studied (Corbus et al, 2004, 2005). However, most of these other turbines furl horizontally, and no other furling wind turbine allows for the furling wind speed to be adjusted. This unique design feature has allowed the HR3 turbines to survive the high wind speeds at BI. While it is unlikely that any other small furling turbine currently on the market could survive the high wind speeds at BI, the new STORM turbine by Southwest Windpower (SWWP), which does not use furling for rotor over-speed control, could be a possible replacement candidate for the HR3 and is discussed in the next section of this report.

The HR3 turbines at BI have had mixed success in terms of their maintenance requirements. While they have been able to survive the high wind speeds and the blades have held up remarkably well, there are two persistent maintenance issues: 1) thermal degradation and failure of the insulation at the generator wire to down-tower wire crimped connection; and 2) insulation failure of the field coil wires where they make a sharp bend in the wire (perhaps due to wear or thermal degradation). To address these persistent issues, the furling wind speed of the turbines has been "tuned" so that the turbines furl at a lower wind speed than shown in Figure 1, and produce less current. This has been accomplished by reducing the furling spring tension and results in limiting turbine output to around 1.8 kW, or approximately 60% of rated power. This has reduced the need to routinely change out these wire connections, thereby increasing turbine availability and extending the lifetime of this part of the turbine.

When these two problems resulted in a generator failure, the generator would be sent back to Northern Power Systems for repair. The repairs typically consisted of rewinding the generators if the field coil wires could no longer be extended. Northern Power systems would also clean the turbine, change the brushes, and conduct other routine maintenance. Each year one turbine would be sent to NPS for routine preventative maintenance, and any other turbine that experienced a failure during that year would also be sent. The need to send the turbines back to Northern Power Systems has been reduced because the turbines have been de-rated and most of the problems described have been mitigated. However, there is still a need to develop an alternative preventive maintenance and repair plan for the wind turbines now that NPS no longer provides this service.

The wind turbine towers are maintained by the McMurdo riggers that visit the site several times a year. These riggers have done a good job of maintaining the guy wires and towers. Although the guy wire tension is somewhat looser than guy wire tension guidelines in warmer climates, it is appropriate for the harsher climates of BI, and no problems with the towers have been reported.

Telecommunications personnel under the direction of Bill Nesbitt, who has been working at McMurdo for 18 years and has a long history with the HR3 turbines and a good understanding of their operation, are responsible for the repair and maintenance of the turbines when they are taken off the tower. This includes maintenance due to failure and preventative maintenance. They are also responsible for the electrical part of the wind systems, including the wind turbine controllers and rectifiers, and any adjustments to set-points on the turbine controllers such as the field current adjustment.

The riggers are responsible for maintenance of the wind turbines on the tower, as well as the towers, and for adjustments to the torsion spring that controls turbine furling. The riggers conduct all wind turbine maintenance while the turbines are on the towers unless there is a problem of sufficient magnitude to require removal. The rule of thumb is that if the turbine has not seized, they generally will not take it down. Coordination between these two groups, who often have high turnover among personnel, is important.

It was reported that in the recent past a new telecommunications engineer had made adjustments to the set-points of the wind turbine field current that resulted in several generator winding failures after the furling tension had been re-set by the riggers to prevent the generator problems. The engineer was attempting to garner increased power from the wind turbines and was not aware of the solution that had been reached to prevent these problems (i.e., de-rated turbines with specific torsion spring furling adjustment). This event highlights the need for adequate training for new personnel on the operation of these unique wind turbines. It also highlights the importance of good communications between the telecommunications engineers and the riggers that both work on different aspects of the turbines.

5.3 Solar Panels

The BITF PV system is comprised of Solarex MSX64 and MSX60 polycrystalline PV modules. There are 212 solar panels, rated at 10-kW, (13-kWpeak @ standard test conditions [STC]). The panels are fixed to the roof of the BI facility in a horizontal orientation so as to prevent damage from the high winds. The panels are guaranteed for 20 years, which means that their output should not drop below 80% of their maximum rated capacity until after 20 years. The PV array is configured into three subarrays: subarray A is 14 groups of 2x3 MSX60 modules, equaling 84 modules and 5040 Wpeak (Wp); subarray B is 8 groups of 2x3 MSX60 modules, equaling 48 modules and 2880 Wp; and subarray C is 10 groups of 2x3 and 5 groups of 2x2 MSX64 modules equaling 80 modules and 5120 Wp. Each subarray is connected via mercury contactor and breaker to the 24-volt bus, and the PLC monitors the bus voltage and disconnects the PV array when the battery voltage becomes too high.

An inspection of the PV system showed that the panels are holding up remarkably well in the harsh environment of BI. The anodization on the windward side of the PV system has been eroded by wind blown debris, but inspection of the panels showed that none were currently damaged and the erosion has been limited to the upwind edge of the system. Although there were reports of panels that were damaged by blowing rocks since the system was installed, these were isolated instances and this is not seen as a major problem. Inspection of the PV panels showed that they were dirty and should be routinely cleaned to maintain optimum overall efficiency of the PV system.

5.4 Diesel Generators

There are three Yanmar 16-kW single phase diesel generators (diesels) that are housed in the generator room. Dispatch of the diesels is controlled by the PLC. Only one diesel is used at any time to power the system, with the other two serving as backup and spare respectively. The PLC dispatches the diesels in sequence to ensure that no one diesel gets significantly more run time hours than any other. Technicians lock-out diesels during maintenance to prevent automatic dispatch by the system.

The AC current from the diesel generators is rectified to DC current and used to charge batteries and run DC loads, or is converted back to AC current by the inverter to run AC loads. AC electricity routed through the inverter incurs about a 25%–30% rectification/battery conversion/inverting loss when the power is rectified to DC, stored in the batteries, and then inverted to AC power.

AC power from the diesels can also be switched upstream of the rectifiers and used by up to two AC glycol heaters, rated at 5 kW and 10 kW, to meet space heating demands of the diesel room, battery room, and control room at BI. While this is a remarkably inefficient way to produce heat, it has been a reliable method of space heating. Jacket heat from the diesels is recovered and also used for space heating. Space heating for the living quarters attached to the power system building is generated by a separate means.

Inspection of the diesel room showed that one diesel was currently locked out for maintenance. The diesel room is slightly undersized for the diesels and there was evidence of an historic exhaust leak. The Yanmar diesel, which is no longer manufactured, is an inexpensive marine diesel that has good fuel efficiency. The main bearings for the diesel are molded into the block and therefore cannot be replaced. The Yanmar diesels are rated for 10,000 hours of use each, but with the good maintenance provided at BI have been able to go much longer. Two of the three diesels have exceeded this value by at least 50% and should be replaced soon. Although the third diesel (#1) had been recently replaced, it was also approaching the 10,000 hour mark. These diesels are not common in the RPSC fleet as it was reported that there are only four Yanmar diesels in all of McMurdo, including the three at BI.

The diesels run on AN8 fuel. The fuel is traversed over from McMurdo station in the winter because the ice is harder than in the summer. There are four 5000-gallon fuel tanks on site. Fuel and diesel run-hour logs from 10/12/2003 to 1/7/2006 were obtained from the BI camp manager, Tony Marchetti, and are shown in Appendix B. Tony Marchetti is the operator for the diesels during the summer months when the facility is manned. Analysis of the fuel logs shows that average monthly fuel use is approximately 582 gallons, ranging from an average of 459 gallons during the summer of 2003 up to an average of 768 gallons in 2004. This variation in the fuel use corresponds to variations in the run hours of the diesels. Fuel and diesel run hour logs were not available for previous years.

The percentage of time that a diesel is running, assuming that only one diesel runs at a time, was calculated from the logged diesel run hours and was calculated for the summer and winter seasons. The average percentage of time a diesel was running varied from 55% in the summer of 2003/2004 to a high of 93% in the winter of 2003. This data is summarized in Table 2. It appears that the diesels ran more than usual in 2003-2004 because the batteries were dead and could no longer hold a charge. A large heating requirement can also trigger extended diesel run time, as well as a large demand for AC power for maintenance and construction personnel.

Table 2. Diesel Run Hours

	Total run hours all diesels	Percent diesel run time
2003 Austral winter	5417	93 %
2003-2004 Austral Summer	1597	55%
2004 Austral Winter	4347	75%
2004-2005 Austral Summer	2203	76%
2005 Austral Winter	3609	62%
2005-2006 Austral Summer (up to 1/7/2006)	1579	72%

The power from the diesels can be used in three ways: 1) charging batteries for system loads, 2) providing for space heating of the facility, and 3) meeting AC loads directly for maintenance and construction personnel. Historic data from 1999, the last year that monthly summary data was available, is presented in Table 3 and shows how the power from the diesels was used according to the three categories. Also shown are totals dating back to June, 1998. The data shows that the diesels are used a lot for both heat and AC power.

Table 3. Power from the Diesels from Archived Data from 1999

Diesel Runtimes (hrs)									
	Monthly					Totals To Date			
Diesel	Heat *	Charge *	AC Power *	Total		Heat *	Charge *	AC Power *	Total
1	0	18	0	18		300	1670	775	2860
2	192	24	0	216		425	1231	270	5908
3	152	284	0	436		433	897	666	4418

Figure 2 shows a comparison of the amps out of the wind generators, PV, and diesels for the same month of September, 1999. A review of previous months shows that the breakdown of amps out of the different power sources is typical for the BI hybrid power system. One of the primary goals of a hybrid power system is to maximize the generation of power from renewable energy sources to thereby reduce diesel fuel consumption and maintenance by reducing diesel runtime. Based on the diesel run time hours analyzed and the data from 1999, this is not happening for the BI hybrid power system.

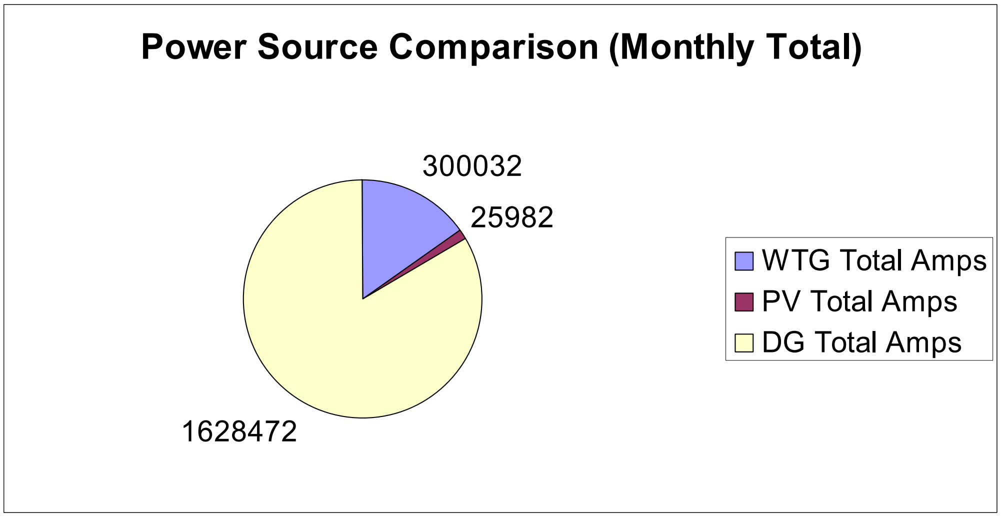

Figure 2. Power Source Comparison between Wind (WTG), PV, and Diesel (DG) from September, 1999

Maintenance of the diesels is conducted by the Vehicle Maintenance Facility (VMF). The BI camp manager, Tony Marchetti does a good job of handling any emergencies with the diesels, keeping fuel and run hour logs, and initiating oil changes and maintenance during the Austral summer when the facility is manned. Logs for the diesels were analyzed, and it appeared that all required maintenance was performed per manufacturer recommendations (e.g., 1,000 hour preventative maintenance). Log book entries contain the date and run hours of the diesel as well as good descriptions of servicing, but should also contain the name of the person making the log entry.

5.5 Batteries

There are 96 GNB Absolyte IIP (model number 3-75A27) six-volt batteries connected to the DC bus of the BI hybrid power system. The batteries are approximately 15,834 amp-hours at a discharge rate of C/48 (1180-amp-hours at an 8 hr rate). A C/48 rate corresponds to the batteries being discharged in 48 hours, whereas a C/8 rate corresponds to an 8-hour discharge; the faster the discharge the less the energy a battery bank can deliver at a given temperature. The batteries are configured in 24 parallel strings of four 6-volt batteries in series. There are three absorbed glass mat, lead-acid 2-volt cells in each enclosed 6-volt battery. This battery type is characterized by long life under deep discharge (i.e., up to 80% depth-of-discharge) and thus is a very good choice of battery for this type of hybrid power system.

The batteries were recently replaced with an updated version of the GNB Absolyte IIP battery. Half the batteries were replaced in the Austral summer of 2003– 2004 and the other half were replaced in the Austral summer of 2004– 2005. It is unclear from the available monitoring data just how long the batteries had been “dead” before they were replaced. (A battery is defined at its end-of-life when its capacity is less than 80% of its rated capacity). It is possible that the batteries had reached their end-of-life for a significant period of time and the system was relying mostly on diesel power, however, no diesel run hours were available from 1999– 2003 to evaluate exactly when the batteries reached their end-of-life. The percentage of time the diesels were running went from 93% in the Austral summer of 2003– 2004 to 55% in the Austral winter of 2004. It was unclear if the 93% was from a dead battery bank or from the diesels being run more during the change out of the batteries when only half the battery bank was working. A battery bank at low capacity will result in both more frequent generator starts and increased losses due to increased internal resistance.

Replacement battery costs are typically the most significant single maintenance cost for hybrid systems with battery storage, and this is especially the case with the BI hybrid power system because it contains a very large battery bank. The total replacement cost of the batteries was difficult to estimate: the capital cost of the batteries themselves was quoted at between $84k and $100k, but that did not include the cost of transporting the batteries. Transport costs (at 0.15$/lb) would cost about an extra $6000, plus handling of the batteries in Christchurch. Also, 40 of the batteries had to be flown in due to the complete failure of the battery bank, adding additional costs.

All battery voltages were checked during the inspection of the batteries. With the exception of one battery, all batteries were within 0.10 tenths of a volt of each other. The one battery that was out of tolerance range was marked and should be checked after battery equalization.

One aspect of battery maintenance that has been overlooked in the BI hybrid power system is battery equalization. Battery equalization is an extended charge to a voltage level above the floating point of the battery. This extended charge reduces any stratification of the electrolyte, which is more important in flooded lead-acid batteries but is also present in sealed absorbed glass mat batteries like the Absolyte IIPS at BITF. Battery equalization has been shown to prevent premature failure of sealed batteries sealed like the Absolyte IIPs (Hund, 1996).

A BTech battery monitoring system was previously hooked up to the old batteries but was never reconnected when the new batteries were installed. The BTech system can be used to monitor voltage of individual battery cells within the battery bank and identify battery cells that start to have a change in internal resistance.

5.6 Inverters

There are three Design Unlimited Inverters (DUI) used to power AC loads at BITF. Two of the inverters are used to supply power to the AC telecommunication loads (model DUI-24/220B1NT) and are rated at 3.6 kW each, with one inverter serving as a backup for the other. The secondary inverter has a sense line, and if the primary inverter looses power, the load automatically shifts to the secondary inverter without loss of load. The PLC determines which inverter will serve as the primary, and this role is alternated between the two inverters to ensure equal exercise. The third inverter (model DUI0-24/3200) is rated at 3.2kW and is used to power domestic loads primarily during the Austral summer months when the facility is manned. These inverters have a good reputation, are very reliable, and were in good condition, but they should conservatively be changed out in the next 5 years as they typically have a useful life of no more than 20 years.

5.7 Programmable Logic Controller (PLC)

The PLC is an Omron Programmable Controller SC1000. The PLC runs the ladder logic that is programmed with Syswin software. There is a custom WonderWare screen, originally programmed by NPS, that provides a user-interface to control the system remotely or at a computer located in the control room at BI.

NREL has had first-hand experience testing NPS hybrid systems built around this same time utilizing a similar PLC and Wonderware interface (Corbus, 1996). The BITF system is more complex because, in addition to the hybrid power system controls, it includes sophisticated heating and ventilation control and load shedding control based on assigned load priority. There is no backup PLC, hence, the PLC system is vulnerable to a complete system shutdown in the event of catastrophic PLC failure.

The PLC is the “brains” of the hybrid system and is programmed using a ladder logic control scheme. The PLC controls functionality of the system including but not limited to: monitoring power sources to maintain battery voltage at a safe level; dispatch of the diesels; control of state changes for the system; rectifier and heater control; control of the wind turbine dump loads; load shedding according to load priority; environmental heating and cooling; glycol pump sequencing; monitoring of system power flow parameters and environmental conditions; monitoring of alarm indicators and faults; remote communication of system faults; AC inverter and transfer switch control and status; and PV voltage connect/disconnect and low power shutdown. This list illustrates the level of detail and complexity for the BITF hybrid power system controller. An overview of the BITF PLC control is given in Appendix C.

The controller keeps the highest priority loads on line as long as possible in situations of low power. In situations of declining battery voltage, the controller disconnects the lowest priority loads first to ensure that the highest priority loads remain connected as long as possible. The highest priority loads are taken off line only after battery voltage drops below the lowest set point. The loads are divided into three different prioritized levels: Priority 3 — lowest priority (first load dropped); Priority 2 — medium priority (intermediate loads dropped, essential to maintain service); and Priority 1 — highest priority (primary systems, last dropped).

A complete description of the control system functionality is beyond the scope of this report. Both the BITF Software manual and the BITF Engineering manual were reviewed in depth to get a good working understanding of the system. Unfortunately, a shortage of time at BI prevented extended evaluation of the controller system functionality and complete familiarity with all the system states. However, a recently conducted, detailed review of the Black Island SC1000 System Test Plan (Timber Line Electric and Control Corp., 2005) showed only three out of more than 150 PLC tests had failed. The tests that failed were not indicative of any major shortcomings in the PLC.

The remote interface for the BITF environmental and power system, originally written by NPS, uses Wonderware software to provide an interface to the PLC system that can be used remotely or locally to monitor and control the BITF system. A computer located in the communications room at BITF provides a local interface to the system, and a computer in the communications satellite room above the firehouse at McMurdo base provides a remote interface. The Wonderware system is well suited to the application and provides the user with all the available information needed to monitor the system and also provides for emergency notification during alarms states. It is recommended that remote interface software that allows personnel to dial into the system from specific computers, such as the computer programs Timbuktu or PCAnywhere, be used. This would allow personnel responsible for the system to access the BITF Wonderware interface from their desk computers with appropriate password approval without having to travel to the communications room.

Lack of sufficient time at BITF prevented a thorough assessment of the monitoring system, but it appears that certain sensors for the monitoring system are out of calibration. No specific calibration plan for sensors, such as current, voltage and temperature sensors, was found for the monitoring system. Calibration of these sensors is important, especially as the system is more than 10 years old.

The PLC program for the BI hybrid system was originally written by NPS, and the system has been continually updated with help from both NPS and Timber Line Electric and Control Corp. The amount of time writing, debugging, and continually updating the PLC is an often overlooked work effort with any hybrid system and has been challenging for the BI hybrid power system because of the complexity of the system. There is a lot of good work invested in the development of the PLC by personnel very experienced with the system. It would be important to use as much of the existing knowledge and experience that went into the current PLC development for the design of a new system. This would reduce PLC development costs as well as the risk that comes with the design and implementation of a new hybrid system controller.

5.8 Balance of Power System

The balance of power system refers to all the other components in the system, including but not limited to rectifiers, heaters, dump loads, dampers, wiring, fusing, terminal connections, switches and contactors, grounding, all DC and AC bus connections, battery chargers and any other related equipment. Inspection of the system showed no irregularities and the system appears to be well maintained, although there was not enough time to conduct a thorough evaluation of the grounding system.

The DC bus is a 24-volt system. Most DC hybrid systems of this size are 48-volts, and the 24-volt system results in larger wire sizes and is not optimal for many of the DC telecommunication loads. The system voltage appears to be a "holdover" from the old ORMAT system. There are some DC/DC converters that are used within the system to convert the 24-volts to other voltages. All the dampers contain 24-volt motors, and they were reported to have special maintenance requirements.

5.9 Heating and Ventilation System

The heating and ventilation system control is comprised of numerous heating and cooling scenarios designed to keep the battery room, communication room, and diesel room temperatures within user-defined temperature ranges.

Space heating is supplied by converting the diesel power into heat and by recovering jacket heat from the diesels. AC power from the diesels can be used to provide power to up to two AC glycol heaters rated at 5 kW and 10 kW to meet space heating requirements of the battery room, diesel room, and communications room. Three 250-gallon tanks for glycol are located in a room adjacent to the diesel room (the room was originally intended for storage), with no secondary containment provided should the systems ever have a leak.

The PLC commands heat based on thermal set-points and temperature measurements in each room. If the AC utility load is less than 100 W, then 15 kW of heaters is enabled if needed, if the AC load is greater than 100 W and below 4800 W, then 10 kW of heaters is enabled if needed, and if it is above 5200 W but below 9800 W, then 5 kW of heaters can be enabled. If the AC load is above 10,200 W then no heaters are enabled. Waste heat from the communications equipment is typically sufficient to meet heating requirements in the Austral summer with the Glycol system being typically used for heat in the Austral winter.

Cooling and heating of the various rooms is controlled by complex ladder logic routines within the PLC that control the fans and dampers between the various rooms and provide for protection against overheating and overcooling with redundant protection in many cases. This complex PLC code has been refined and improved since the original code was written.

5.10 Building and Space Requirements

An upgrade or a new hybrid power system at BI may require additional space. This is also true for an upgrade to the communications system. Therefore, it is important to evaluate the space for the existing system.

The diesel room is somewhat small for the three diesels it houses, but it may be possible to expand the building out to the east with an extra panel. The battery room has adequate space for the large battery bank that it contains, but there is very little extra wall space left for mounting any new equipment. The communications room has room for only 2 or 3 more racks. There appears to be a lack of storage space within the three rooms, as it was reported that the small room containing the glycol and fire suppression system was originally intended for storage. Note that this report does not include a review of the fire suppression system. The existing building is a prefabricated Bally building and can be added onto in a modular fashion.

6.0 Future System Upgrades/Modifications

6.1 Overview

The BI hybrid power system is about 13 years old, and therefore, it is prudent to make an assessment of the state of the system as a whole as well as the individual components. Future plans to the communication system at BI, although still in the planning stages, could result in a small increase in the load. However, there is still some uncertainty on future load growth as part of the NPOES system expansion, so the suggested modifications are based on the BI hybrid power system and heating and ventilation system as presented in the previous section of this report with the existing load.

The BI hybrid power system and heating and ventilation system are custom built systems that have had significant design changes and improvements since their original installation. There is no commercially available "packaged" hybrid power system that could be purchased to replace the system. Any new system, although comprised of individual pieces of commercial equipment as the original system was, would require a special design. The experienced gained in designing and operating the existing system would greatly help facilitate the design of a new system.

Several different upgrades, including a new system, are discussed in this section of the report. Three different alternatives are evaluated and include: 1) minor upgrades to the system; 2) significant changes to the system; and 3) a complete new system. The alternatives presented encompass a wide range of modifications that could be made to the facility and were chosen as three logical "scenarios" that reflect a gradual change from simple and less expensive to more complex and more expensive. Modifications for different scenarios could be combined, and not all changes need be made within a scenario. Some changes could be phased in over time, whereas other changes would best be done at one time. The three scenarios were chosen as a logical way to group the different modifications. They are presented here to show the range of possibilities. The final decision will be influenced by factors not known at this time, including available funding, future changes to the communication system at BI, and potential future operational changes at McMurdo station.

6.2 Scenario 1 – Minor Upgrades to the Existing System

Scenario 1 consists of minor upgrades to the existing power system and heating and ventilation system. The small changes to the system would essentially keep the system functioning as it is with small improvements in system efficiency. The existing PLC and Wonderware interface would be used to control the system and the following upgrades would be made to the system: "hot swappable" PLC; maximum peak power tracker for PV system; new diesel gensets; re-connect the battery monitoring system; and minor set-point changes to the PLC. No major changes to the heating and ventilation system would be made. A preliminary 1-line electrical schematic for the system is contained in Appendix A.

A hot swappable PLC would provide redundancy to the existing PLC should the PLC fail for any reason. Should a failure occur with the existing PLC, the failure would bring the entire system down. A redundant PLC would take away the risk of a single point failure within the PLC that increases with the age of the system. Sample specifications for a hot swappable PLC are contained in Appendix D.

A maximum peak power tracker (MPPT) would increase the output of the PV panels by approximately 25%–30%. All PV modules have a maximum power point where the module voltage times the module current equals the maximum power. However, a PV system's maximum power point continually changes based on temperature and insolation. The MPPT controller tracks the maximum peak power and changes the voltage that the PV panel sees to the corresponding peak power voltage.

Figure 3 shows the operating characteristics from the manual for the MSX-64 PV modules that are used at BI. The voltage at maximum power is 17.5 volts at 25 degrees C. With two panels connected, as is the case with the nominal 24-volt BI system, the maximum operating voltage is 35 volts, but the typical operating voltage of the nominal 24-volt battery bank at BI is in the 25–28 volt range, depending on the state-of-charge (SOC) of the battery bank 3. This difference in voltage results in about a 25% loss in PV power output depending on battery bank SOC. Furthermore, as shown in Figure 3, the PV modules rated power is greater at lower temperatures like those found in BI.

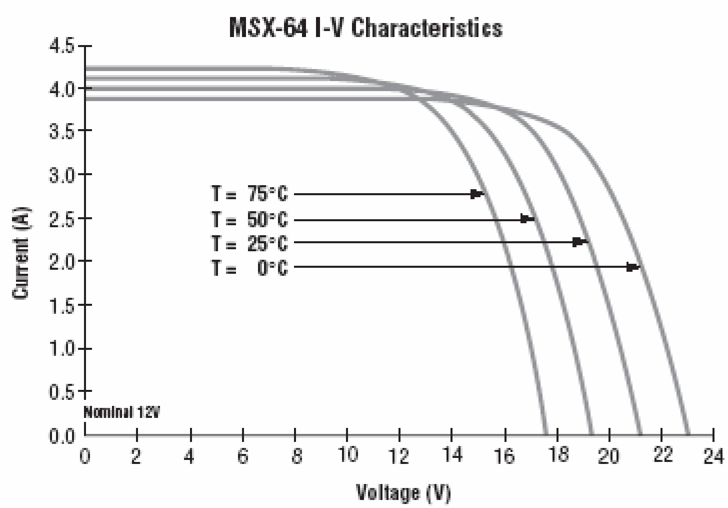

Figure 3. Operating Characteristics for the MSX-64 PV Modules
(Source: Solarex Manual)

The Yanmar diesels are rated for about 10,000 hours of use, and two of the three diesels are currently over this limit at about 18,556 and 15,793 hours (as of 1/7/06) and quickly approaching their end-of-life and should be replaced soon. The other diesel is newer and has 7,661 hours. Most of the diesels at McMurdo are Caterpillar diesels, so Caterpillar is a logical choice for a new generator from a parts and maintenance standpoint. However, Caterpillar's small diesel generators are not necessarily the most robust, hence the procurement for small diesel generators at BI should include quotes from several different vendors. Catalog cuts for several good small diesel vendors are contained in Appendix D.

The BTech battery monitoring system should be reconnected to the battery bank and used to monitor the battery system. The Btech system was connected to the old system and when the new battery bank was installed the batteries were a different size and the wire lengths to connect to the batteries were not long enough. Longer wires should be used to connect the batteries – they can be lengthened by adding a longer wire from about the halfway point of the existing wires, where the in-line fuse is installed, and running this from the fuse to the battery cells.

The BTech system can be used to monitor voltage of individual battery cells within the battery bank and identify battery cells that start to have a change in internal resistance. A change in a cell's internal resistance can lead to eventual battery failure because that battery string will get more current depending on the internal resistance difference, and this difference can lead to a positive feedback that increases the current to the battery, and that can lead to premature battery failure. This is not as big a concern for the BI battery bank compared to many other battery banks because it is so large, and hence, the charge currents are small. Nonetheless, monitoring battery cell voltages with the BTech system and equalizing those batteries that deviate in cell voltage will extend the life of the battery bank and maintain high battery bank efficiency. It will also allow the user to predict when the battery bank will reach its end-of-life. Ironically, this did not occur with the previous battery bank because when the monitoring system was installed, it immediately informed the operators that the batteries had already reached their end-of-life.

There has been a lot of analysis regarding the control and dispatch of wind-solar-diesel hybrid systems (Barley, 1997). One of the lessons learned has been to maximize the use of renewable energy input to the system. This could be done for the BITF by increasing the high voltage setpoint on the PV disconnect in the PLC and on the wind turbine charge controllers. The battery bank is so big that these renewable energy systems can charge the system to a higher voltage level, which is good for the batteries because it gives them a small boost charge and prevents the renewable energy from being wasted. As with all batteries, care should be taken to never overcharge the batteries.

6.3 Scenario 2 - Significant Changes to the Existing System

Scenario 2 consists of making significant changes to the existing system, including the heating and ventilation system, but not installing any new wind turbines. New inverters are installed that can supply AC power directly to AC loads and that can act as a current source and automatically synchronize to the diesels when they are running (diesel on) or act as a current source and control frequency when the diesels are off. The inverters control the flow of both AC and DC power on an upgraded 48-volt DC bus. An additional PV capacity of about 2.5 kWs is installed on the roof of the communications room. The HR3 wind turbine connections are upgraded so that rated capacity can be achieved. The existing PLC and Wonderware interface are still used for this scenario, but modifications are required to both. All the changes to the system described in Scenario 1 are also assumed for Scenario 2. A preliminary 1-line electrical schematic for the system is contained in Appendix A.

A significant change in this scenario is that the AC glycol heaters are no longer used to supply space heat; instead, a high-efficiency boiler is used to supply space heat using the same glycol loop. This increases the efficiency of the system dramatically because AC electricity is no longer used to generate heat, although this system can be kept in place and used as a backup should the boiler system fail for any reason. It should be noted that this marked increase in heating efficiency should be compared to the current heating efficiency that is limited to around 60% at best. The jacket heat from the diesels is still used as the first means of providing heat when the diesels are running. Product specification sheets are shown in Appendix D for various boilers and include the Espar heater, which has been used successfully on Mt. Newall. The boiler is controlled by the PLC, which will need to be reprogrammed and can include a backup condition whereby the AC glycol heaters are still used should the boiler fail for any reason.

State-of-the-art inverters are capable of supplying AC power directly to an AC power bus from an AC source, such as a diesel generator, to meet AC loads and simultaneously rectifying AC power to DC power to meet charging requirements of batteries and DC load requirements. A 48-volt DC bus typically is used to reduce wire size and directly meet 48-volt DC communication loads. Several inverters can work in parallel with one inverter acting as a master to control frequency. The inverters are very proven and reliable in this type of application. Product specification sheets for inverters are contained in Appendix D.

Appendix A shows a 1-line electrical schematic of the Scenario 2 system showing the power from the diesels being connected directly to the new inverters/rectifiers and the connection of the inverters to the 48-volt DC bus. The existing batteries, wind turbines, and PV system are all re-configured to a 48-volt system. This can be done by rewiring the existing systems and changing fuses and contactors, and also changing set-points in the PLC and wind controllers. The MPPT is shown connected to the PV system as described in Scenario 1. Approximately 2.5 kW of capacity is added to the PV system by installing PV modules on the roof of the communications room. Although there is some shading from the adjacent dome, the sun is often up for 24-hours in the Austral summer and the shading is not very significant.

The connection on the HR3 wind turbine where the generator wires are connected to the down-tower wires would be upgraded to prevent future failures, and the field coil wires would be modified to prevent failure where they make a sharp bend in the wire. These modifications would allow the turbine set-points to be modified so as to increase the turbine output from 1.8 kW to near their rated capacity of 3.0 kW. These changes would have to be done in a controlled manner on one test turbine and then evaluated.

The loads are divided into the same three priority loads as before, except they are 48-volt DC or 120-volt AC loads; some loads may have to remain 24-volts DC (e.g., the motor for the antenna) and will require a step-down transformer. The glycol heaters are still in the system as a backup (these could be removed at some point after boiler reliability is demonstrated in high winds). Lighting is changed out to high efficiency 48-volt lighting and proximity sensors are put on all lights. Dampers and fans are also changed out to 120-volt or 48-volt systems. (Note: the Scenario 2 system could remain a 24-volt system, as the inverters can also be specified at 24-volts, but because major rewiring will be required, it seems prudent to change to 48-volt.)

6.4 Scenario 3 – New System

The new system contains everything listed in Scenario 2 but also contains new wind turbines, a new PV system, additional building capacity, and a new PLC and remote interface. A preliminary 1-line electrical schematic is contained in Appendix A.

An extensive investigation into commercial wind turbines that could be used at BI produced only one potential candidate: the STORM turbine. Turbines that furl horizontally and for which the furl tension cannot be set would not hold up to the strong winds at BI. The STORM turbine does not furl in high winds but instead uses stall control and solid-state control to load the alternator to maintain rotor speeds in high winds. Specifications for the STORM turbine are shown below in Table 4.

Table 4. Specifications for the STORM Turbine

Rated Capacity	1.8 KW
Weight	65kg (160 lbs)
Swept Area	10.75 m2
Rotor speed	0 – 280 rpm
Alternator	Neodymium based brushless/slot-less design
Grid Feeding	SWWP Inverter 120/240 VAC 50-60-/HZ
Cut in Wind Speed	2.5 m/s
Rated Capacity	11 m/s
User Control	Wireless 2-way remote

The STORM turbine, manufactured by Southwest Windpower in Flagstaff, Arizona, is a new turbine rated at 1.8 kWs that will be commercially available in September, 2006. The turbine was designed in conjunction with NREL and cost shared by DOE (as was the HR3 Turbine). The turbine has swept blades and is installed on a non-guyed tower, which results in a much smaller space requirement than the guyed HR3 turbine towers. The STORM turbine cuts in at a low wind speed of 2.5 m/s and is designed to maximize energy capture in low wind speeds, which would be effective in the Austral summer months when the wind speed can be lower. Test data for the turbine from the NREL test site is shown in Figure 4, and a picture of the turbine is shown in Figure 5. The turbine's power curve shows effective control of the alternator during stall regulation and has been tested to winds exceeding 60 m/s.

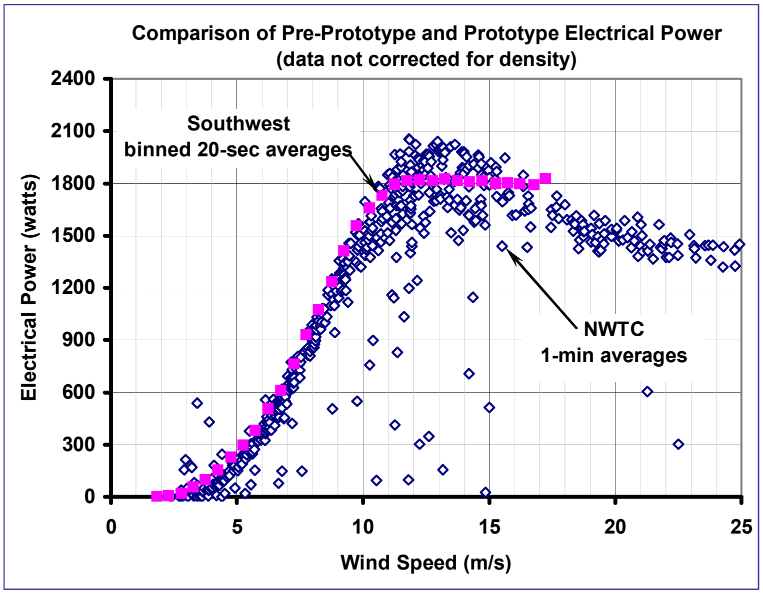

Figure 4. STORM Test Data from NREL Test Site

Figure 5. STORM Turbine Installed at NREL Showing Swept Blades

The STORM turbine was designed for a wind speed of 40 m/s. There are large safety factors built into the design of the turbine and the tower, but the loads on the turbine go up significantly as the wind speed increases. To estimate the loads on the STORM at the higher wind speeds, computer simulations were run that were originally used to design the turbine at the lower wind speed, but they were run at a wind speed of 85 m/s with a turbulence spectrum representative of BI. The

STORM was modeled using the FAST computer code (Jonkman, 2004) to calculate aerodynamic forces. FAST, which was developed by NREL, is the primary aeroelastic simulator used by the U.S. wind industry to model small wind turbines. The results of the FAST model are shown in Appendix E and show peak loads for the turbine in a parked state (i.e., no rotor RPM).

As with the original installation of the HR3 turbines, the installation of the STORM turbine at BI would be considered a BETA test of the turbine, because the turbine cannot be tested anywhere else at those wind speeds. The highest typical wind speeds at the NWTC test site are gusts of 100 mph, much lower than the wind speeds at BI. To install the STORM turbine at BI would require some minor cold weather modifications, such as changing bearing grease specifications for colder temperatures. If necessary, the STORM blades could easily be shortened to reduce the structural loads on the wind turbine system. It is recommended that one STORM turbine be installed immediately to test the turbine at BI and to evaluate its performance. A review of the turbine's performance at BI could lead to the STORM's use for future polar applications in addition to BI. The STORM turbine currently lists for $5000, although a modified turbine for the BITF could cost slightly more.

The existing PV system is rated at a 20-year lifetime, which leaves approximately 7 more years before the PV system peak output would be expected to fall to 80% of its rated output. Although not a critical upgrade from a time perspective, it may be convenient from a project implementation and funding standpoint to replace the PV if a new system is installed in the next 5 years.

A new power system would not require any more space than the existing power system, but adding space would alleviate the cramped feel of the diesel room. Upgrades to the communication room may require additional space. Additional space for the power system could be achieved by expanding the diesel and storage room out to the east by adding additional panels. Additional space for the communications room could be created by adding a second floor above the existing communications room. A second floor on the communications room would be on the downwind side of the building from the prevailing wind direction and would be in the wake of the existing building and hence, wind speeds would be reduced significantly from the wind loading on the upwind side of the existing building. A steel support structure would be required to support a compatible, modular Bally building, as the existing building would not meet the structural requirements of a second floor. The existing prefabricated Bally building lends itself to expansion in a modular way at a manageable cost.

A new PLC and remote interface is included in the new system. The PLC code would utilize the design, experience, trouble shooting, and lessons learned from the existing PLC and remote interface. Specifications for the monitoring, control, alarms, and communications for a new system would be compared to the existing PLC functionality. Much of the ladder logic from the existing system could be used in the new PLC code, but the redesign of the PLC would allow for modifications to the control system that would increase system efficiency, reliability, and user friendliness, and also use the latest advances in PLC development. It would be very important in the redesign of the PLC and remote interface not to "reinvent the wheel" for the BI system. Starting from scratch with a new controller development would be costly, time consuming, and probably decrease system reliability in the near term.

Any new power system at BITF should be monitored to verify that the system is working as designed. Monthly reports on the existing NPS system at BITF were put together by NPS through 1999, after which they appear to have been stopped. Table 2 and Figure 3 contain some of that monthly monitoring data. Monthly monitoring reports can be very valuable in assessing system performance and should contain data on renewable energy resources, e.g., wind speed and solar insolation, as well as power output of diesels, wind generators, and PV. Plots of battery voltage allow for an evaluation of battery state-of-charge. Time series plots allow for evaluation of system state changes. Monitoring a system requires a time commitment to gather and analyze the data, but it is also a great way for users to understand a system. A sample monitoring report from a renewable energy system is contained in Appendix F to show a concise yet informative monitoring report format that could be used as a template for monitoring a new hybrid power system at the BITF.

6.5 Assessment of Fail Safe Operation

The existing PLC has a very good ladder logic program that provides for fail safe operation of the hybrid power system. The PLC code has been refined over the years. A fail safe condition is always available when the system can operate off of the large battery bank and meet critical DC loads should the diesels and inverters shut down. Any new system would be designed with the same fail safe approach. Critical loads would also include 120-volt loads. In the case of an inverter failure, including backup redundant inverters, the system would revert to a diesel-only mode to meet critical 120-volt loads. This has been done on other AC hybrid systems including the NPS PowerCastle system.

6.6 Comparison of Scenarios

Table 5 contains a summary of all the modifications discussed for the three scenarios. The table divides the modifications into the three broad categories: control system, components, and building space. Note that modifications can be combined from different scenarios.

The three scenarios were compared using three criteria, incremental capital cost, fuel savings, and long-term risk, and then scored on a scale of 1 to 10. The incremental capital cost went up from Scenario 1 to Scenario 3 as new equipment purchases were required. The fuel savings went up significantly from Scenario 1 to Scenario 2 with the addition of the high efficiency boiler and then slightly more with the added renewable energy systems. Finally, long-term risk, defined as the probability of system outages, went down with the new system as the equipment in a new system is less likely to fail than the equipment in a system reaching the end of its 20-year lifespan. The short-term risk may actually go up for Scenarios 2 and 3 because any significant changes to a finely tuned system will require some minor troubleshooting during start-up and shakeout of the system.

Table 5. Description of Three Different Scenarios

			Minor Upgrades to the Existing System	Significant Changes to the Existing System	New System
Control System					
	PLC				
		Existing Omron PLC/Wonderware System	x	x	
		New PLC and Remote Interface			x
Components					
	Wind Turbine				
		HR3 (existing)	x		
		HR3 (upgrades)		x	
		SWWP Storm (Modified)			x
	PV				
		Existing Panels (13.04kW)	x	x	
		MPPT Charge Controller	x	x	x
		Additional 2.5 kW Capacity		x	x
		New PV System			x
	Inverters/Rectifiers				
		AC bus powers primary 120-volt loads		x	x
		Existing Inverter/rectifier	x		
		Integrated Inverter/Rectifier		x	x
	DC Bus Bar Voltage				
		24V	x		
		48V		x	x
	Batteries				
		24V	x		
		48V		x	x
	Diesels				
		New Diesels	x	x	x
		Waste Heat Recovery	x	x	x
	Site Heating				
		Existing Glycol System	x		
		High Efficiency Boiler		x	x
Increased Building Size					x
Incremental Capital Cost (0-10)			1	4	10
Fuel Savings (0 - 10 scale)			1	6	8
Long-term Risk (0 - 10 scale)			5	3	2

7.0 Organizational Structure of the BITF

For any power system, timely maintenance is of critical importance. There are numerous challenges to providing good maintenance for the BITF system, among them availability of spare parts, availability of qualified maintenance personnel, and communication of specific maintenance requirements. The management and organizational structure for the BITF plays a key role in addressing the maintenance concerns of the BITF power and environmental systems.

At the BITF there are several different organizations involved with different aspects of operation and maintenance (O&M), system upgrades, fuel delivery, day to day management of the system, and design of future upgrades and/or modifications. All these organizations must work together to coordinate the O&M of a very complex power and environmental system. Added to this challenge is the high turnover rate of some personnel working on the facility. Some of the personnel involved with the system are stationed at McMurdo during the Austral summer, whereas some of the personnel are located in the Raytheon offices in Denver, Colorado, and make visits to the site as required.

Information Technology (IT) is responsible for the communications equipment, including scheduling and repairs, as well as maintenance of the batteries, wind and PV systems, and long-term responsibility for the dome and antennas and all electronic equipment. Site Operations is responsible for the infrastructure of the BITF and the facility itself. The Vehicle Maintenance Facility is responsible for the O&M for the diesels and other heavy equipment such as the forklift. The FEMC is responsible for the glycol system, work orders related to system upgrades, and tracking maintenance requirements. Several contractors are used to provide services for the system, including programming of the PLC.

The BITF lacks a single individual that is directly responsible for the complete operation of the power system. This job usually gets relegated by de facto to the communications technician, but only because he is working on the communications equipment. Historically there has been a high turnover rate among the communication technicians at BITF. This can lead to “brain drain” because it takes time to become familiar with such a complex hybrid power system, and so there are periods where the communication technician is learning about the system and then periods of transition between personnel. The BITF is one of many jobs for the communications technician and so he is only at the site part-time during the Austral summer, depending on the communication work required.

It is recommended that a formal part-time job description be adopted for a communications technician or equivalent. This could be added to an existing job description. This job description would require familiarity with the BITF power and environmental system, knowledge of the PLC and remote interface, and close coordination with all the entities involved with the BITF. This person would have a remote Wonderware terminal at their desk, would check the system daily, and would receive notification via pager of alarms. They would also collect and analyze some of the power system monitoring data and track long-term trends, such as battery condition, wind turbine power output, and diesel run time. This person would be important to the installation and operation of a new and/or modified system to replace the existing system. Despite its age, the BITF hybrid power system is still a state-of-the-art-system and most technicians and engineers would find working with this system rewarding.

8.0 Considerations for Future Energy Upgrades in Antarctica

8.1 Organizational and Regulatory Constraints

Antarctica, as a remote location with harsh environmental conditions, poses a unique engineering challenge for energy systems. Similarly, institutional and regulatory constraints play an important role in the consideration of both energy efficiency measures and the adoption of renewable energy technologies. These factors contribute to both the technological struggles with small-scale renewable systems and the slow investment in large-scale renewable energy systems.

As any observer of White and Black Islands will notice, the environmental conditions in Antarctica can vary greatly over even short distances. For example, the extreme high wind conditions evident at Black Island that scour the surface clean of snow and ice are apparently not also typical of White Island. Similarly, the extreme winds at Black Island are also atypical of sites in the immediate vicinity of McMurdo Station thus alleviating some of the engineering challenges to development of renewable energy projects at the station. The engineering challenges that remain when considering investments in large-scale renewable energy systems are largely confined to the extreme cold, access to the best siting locations, and power quality maintenance concerns when considering substantial contributions from renewable sources.

As is typical with many large organizations, the organizational and institutional structures that govern the USAP system and allow for satisfactory congressional oversight also inadvertently result in long lead times for project implementation. Despite significant and compelling advantages to investments both in renewable energy and energy efficiency improvements to buildings, the numerous requisite levels of approval and demonstration of mission need collectively conspire to discourage development of innovative proposals and solutions at anything but the lowest levels of program operation.

An ironic consequence is that those that are most attuned to the needs of the program at the ground level, best suited to intuit environmental, institutional, regulatory, and structural hurdles, and best positioned to execute programmatic, engineering, or technological solutions, are also those that are least able to propose solutions.

One potential remedy for this constraint is to establish a codified channel through which program operators are able to engage outside entities to interpret and provide expert guidance for evaluation of, and assist in developing, execution plans for novel solutions. There exists a vast body of expertise at all levels of operations within the both Federal government and private industry.

Another area of concern is the regulatory constraints that were originally born from clear need and with good intention that also result in unexpected and unfortunate consequences. An example of how these constraints were inventively addressed so as to arrive at a solution that is efficient, cost-saving, and compliant from a regulatory perspective follows:

Per Aviation guidelines, the tanks at the Marble Point Air Facility must be sump pumped daily to ensure that only the cleanest fuels are used to refuel the helicopters that land at the station. In accordance with environmental regulations, this fuel must be tanked, palletized, and carried to McMurdo Station until it can be shipped back to the United States where it is poured into concrete flaring vaults for disposal.

In fact, this fuel, while unsuitable for aviation from a regulatory standpoint, is perfectly suitable for on-site consumption, especially in furnaces. The personnel at Marble Point recognize this and began consuming this "waste" fuel on-site resulting in a marked decrease in demand for fuel for site operations and a decreased need for shipping all but the foulest fuels back to the U.S. In fact, this abundance of "free" fuel is nearly enough to meet all site needs for fuel provided that modest energy efficiency improvements are made.

Ironically, the site buildings at Marble Point, Antarctica are characterized by building envelope insulation levels that are less than that of the typical new continental U.S. residence. The buildings that populate the site are cast-offs from McMurdo Station because the institutional barriers to requisitions for new buildings are so great. While the fuel savings from even modest insulation improvements would very quickly pay for the improvements, funds for capital improvements and maintenance are of such different colors as to prevent even this obviously prudent and wise improvement.

8.2 Marble Point

Marble Point, being as close to the margin of energy sustainability because of the source of "free" fuel to meet most of their operational needs, may represent some of the best returns on investment for renewables and efficiency improvements of any site near McMurdo.

Among the many innovative energy saving solutions that have been implemented at Marble point are:

1. Grey water evaporation systems utilizing "base load" electricity from the generators.
    a. Generators must be loaded to a minimum level to minimize maintenance requirements
    b. Resistive dump loads that reject heat to the atmosphere are typically used to meet this need
    c. The staff at Marble Point use a resistive load that is coupled with the grey water evaporation tank and thus have invented a productive use for this type of energy that is usually of low value
2. Use of waste fuel in snow melting equipment
    a. Marble Point staff not only use waste fuel for snow melting, but have also discovered ways of minimizing fossil fuel requirements for snow melting by maintaining a minimum level of seed water in the melt tank
3. Utilizing "base load" electricity to keep snow melt seed water warm
4. Use of waste fuel for building heat

As mentioned before, because of the Marble Point staff's inventiveness, much of the site energy demands are already met with waste fuel. Limited additional improvements would provide large returns if the site efficiency could be raised to where all energy requirements could be met with waste fuel. Included among the highest priority improvements are:

1. Improved sizing of diesel gensets
    a. The current diesels are generally oversized for the site load
    b. An energy assessment should be undertaken to evaluate the minimum sized diesel required to meet the load
2. Capture of genset jacket heat
    a. An additional 25%–30% more energy (nearly equal to the amount of electricity generated) could be captured from the engine jacket cooling system, provided a radiant heating system were adopted
    b. In order to minimize losses in the jacket heat system, the generator building should be moved closer to the other buildings
    c. In conversations with operations staff at Marble Point, it appears the generator building was sited distally so as to minimize probability of site conflagration in the event of a generator fire. Siting the generator building downwind of the main building would allow more proximal placement while also addressing this concern
    d. While radiant heating systems can involve more construction and maintenance concerns than electric resistance heating, conversations with engineers that service the Mt. Newell system indicate that the Espar heating system there has

been trouble-free and efficient. Espar (or other) heaters coupled with jacket heat radiant systems would be among the most fuel efficient means of heating

3. Capture of energy from flue heat
    a. An additional 25%–30% more energy could also be captured from an exhaust heat recovery system
4. Use of furnaces for heat rather than electric resistance
    a. With the heating system in operation in the main building during the austral summer of 2005/2006, diesel gensets were used to produce electricity at efficiency rates of 25%–30%
    b. This electricity was routed to the main building where it was used to heat the building with resistive base-board heaters
    c. All Energy Star rated qualified furnaces must have an efficiency of at least 90%
5. Improved insulation on building envelopes
    a. Only the sanctuary building utilizes insulation values that are typically called for in the Antarctic environment
    b. Improving wall thickness of the residences would reduce heating requirements for maintaining comfortable temperatures
6. A better sited grey water evaporation system utilizing a greater surface area
    a. Evaporation rates are proportional to surface area thus using a shallower evaporation pan with larger planar dimensions would improve evaporation
    b. Covering the evaporation pan to contain the heat (while allowing moist air to escape) would reduce heat loss and also improve evaporation rates
    c. Siting the evaporation pan where it does not fall in the shadow of the building and thus would benefit from solar radiation throughout the day would reduce energy requirements for similar quantities of evaporation
7. Improved capture of waste heat from the evaporation furnace
    a. During high evaporation demand periods a furnace is used
    b. Through improved encapsulation, more heat from the furnace could be captured and retained for passive evaporation when the furnace is not running
    c. This can be achieved by building a rock or masonry wall that captures most of the furnace flue gases and constrains them in the area under the evaporation pan
8. Addition of space heaters that are capable of utilizing fuel of very poor quality
    a. Some sumped (and leaked but captured) fuels are of such low quality that they cannot be burned in the existing furnaces
    b. This fuel must be shipped back to Washington for disposal
    c. By adding a waste oil furnace or low tech Preway burner, virtually all fuel could be burned on-site leading to near 100% utilization of fuels unfit for aviation
9. Addition of liquid-fuel-fired cook stove
    a. The cook stove in use during the austral summer of 2005/2006 was an electric range (with no oven temperature control)
    b. Like electric heating from electricity produced by fossil-fueled generator, electric stoves are a low efficiency means of generating heat (currently probably around 30%)
    c. A cook stove that could also utilize waste fuel would further reduce requirements for electricity
    d. While numerous options exist, an example that is found in many European homes is the Aga: http://www.aga-ranges.com
    e. Cook stoves, such as the Aga, can also provide water and space heating
10. Solar Energy
    a. The roof pitches of the buildings at Marble Point lend themselves as good platforms for photovoltaic systems

b. Because the diesels run 24 hours per day, a virtual grid already exists to support grid connect PV
c. Grid connected PV arrays would serve to offset demand for fossil energy and would eliminate the need for batteries and inverters

Marble Point is poised to serve as a small-scale test bed for efficiency and renewable energy improvements in the McMurdo Station area. Because it is manned throughout its service season the technical requirements for a renewable energy augmentation system would be far less than those of the BITF. Because the environmental conditions at Marble Point are far more benign than those at BITF, some of the engineering challenges are reduced. Because diesels at Marble Point run 24/7, the effective AC grid can serve as a simple, reliable backplane for renewables. Because Marble Point is small, contained, and well managed it is ideal for serving as a small-scale test bed for improvements that would also make sense in McMurdo Station. While most of the improvements noted above would provide rapid payback, an energy assessment would provide a quantitative perspective on just how fast these paybacks would occur. RPSC already has an energy management expert on staff and at location that could readily conduct the energy assessment of the Marble Point system.

8.3 Small-Scale Renewable Systems for Remote Camps

RPSC has demonstrated considerable wisdom both by its adoption of small-scale renewable energy systems for remote field camps and through its employment of a full-time small renewables expert. This expert's familiarity with small-scale solar systems continues to provide remote science camps with nearby expertise for the design and maintenance of portable power systems for remote field camps that continue to exhibit good field performance. Unfortunately, while the experience with small solar systems has been favorable, aside from the Mt. Newell system, experience with small wind systems has been mixed.

As mentioned earlier in this report, the environmental conditions of Antarctica are unique and can fall beyond the design parameters of most small wind turbines. From conversations both with the small-scale renewable energy expert and with scientists from the field camps, it appears that only a few models have been experimented with and with mixed success. Unfortunately, this has lead to a lukewarm attitude toward small wind systems in the field. However, the small wind turbine market is constantly changing with new manufacturers and machines arriving on the market yearly. Ensuring that the small-scale renewable expert is equally trained in wind systems would also ensure that only the best suited small wind turbines on the market were installed. A survey of small wind turbines that have been used on the continent and the relative success of each model should be conducted so as to ascertain which models, whether domestically or internationally built, are best suited for the harsh environment of Antarctica.

8.4 McMurdo Station

McMurdo Station, being remotely located, relies entirely on imported energy and thus stands to greatly benefit both from efficiency improvements and investments in renewable energy. However, in the same manner that Marble Point can serve as a microscopic version of McMurdo, and thus as a test-bed for candidate improvements for McMurdo Station, the inverse is also true in terms of the constraints for capital improvements. The same organizational hurdles for capital improvements apparent at Marble Point are also present at McMurdo Station and in a larger scale. Nonetheless, because of the remote location of McMurdo Station, even modest investments in renewable energy systems and energy efficiency improvements are warranted.

McMurdo Station, having evolved from a Navy installation while being the beneficiary of significant infrastructure investments, is also the unfortunate heir to a variety of building types, construction techniques, and building technologies that range from historic to state-of-the-art. In stark contrast, the New Zealand station just two miles away, presents a deliberate, connected, contemporary construction. While recognizing that station operators at McMurdo station make every effort to consolidate personnel during the winter months, additional improvements in building efficiency for the few inhabited buildings during this intensely cold period would contribute to reducing Austral winter power demands.

McMurdo Station, while generally spared from the extreme winds of BITF, does have a good wind resource that, if utilized, would result in significant fuel and cost savings to the program (Baring-Gould, et al., 2005). The Arrival Heights area above McMurdo station is nearby, readily accessed by existing roads, and provides good access to the prevailing winds. Crater Hill, though not as readily accessible and further away, provides even be better access to winds from all directions. Equipment and expertise already located at McMurdo Station are well suited for both installation and maintenance of a large-scale wind facility.

Because of the current accounting methods at McMurdo Station where only the cost of fuel as delivered to the ice pier is factored into the cost of energy and not the cost of storage, delivery, or maintenance, only wind energy is competitive at this point. However, when these other costs are factored into the cost of energy, solar energy becomes more competitive as an alternative energy. Even with the current accounting practices, any renewable source of energy, including solar, should be pursued because of environmental considerations. Antarctica is widely regarded as the last pristine area on Earth, thus, prudence suggests that every effort should be made to reduce emissions from fossil fuel generated electricity and power.

Remote facilities are generally characterized by redundancy. This logical approach is based on statistically determined failure rates and the typically high costs associated with being without service, whether the service is electricity, heat, or water. Similarly, remote facilities are generally characterized by systems that are sized for the maximum demand. While this combination of oversized, redundant systems generally leads to high system availability and productivity, it also comes at excess cost. This is apparent with the diesel generators at Willy's field and with the reverse osmosis desalination system at McMurdo Station.

The energy required to desalinate water is proportional to both feedwater temperature and salinity. Currently the reverse osmosis system in operation at McMurdo Station produces more product than is required on a daily basis. As operators of the water plant describe, turning the system off periodically to save energy ultimately results in lower efficiency because with each on/off cycle, the reverse osmosis (RO) membrane loses efficiency. Discussions with RO experts at the U.S. Bureau of Reclamation confirm that recycling product water back into the feedwater stream to reduce feedwater salinity (raw water blend bypass), and thus efficiency, would be an effective means of reducing overall power consumption assuming an abundance of product water. Concerns must be paid, of course, to the resultant dissolved solids levels to ensure that no unexpected consequences such as membrane scaling, occur.

During the Austral summer of 2005/2006, improvements to the water plant were underway that included the installation of two diesel gensets. The proximity of these gensets lends itself to the use of either jacket of flue heat for preheating of the feedwater. As is illustrated in Figure 6, the desalination productivity is proportional to feedwater temperatures. Feedwater (or permeate) flows are analytically corrected by temperature correction factors. From tables for thin film membranes, this factor can constitute up to a 70% reduction of flow (for near-freezing water vs.

77F water). By utilizing waste heat for preheating, significant gains in product recovery ratios and thus overall efficiency can be realized, even to levels at which the RO system size could be reduced. Again, attention must be paid to any unexpected consequences such as scaling, as scaling is temperature dependent. See http://www.gewater.com/library/tp/700_Six_Pieces.jsp
For more information.

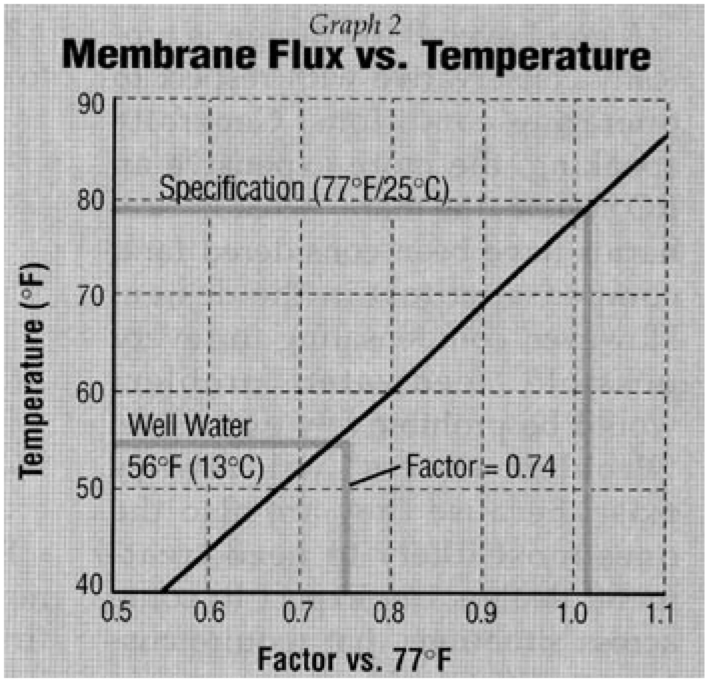

Figure 6. Desalination Productivity Proportional to Feedwater temperature

As mentioned previously, the diesels at Willy's field are grossly oversized. Even the backup equipment is oversized. Instead, a strategy of using more appropriately sized diesels in which multiple diesels (including backup units) can be run synchronously so as to meet extreme load requirements during the Austral summer of 2005/2006 at the McMurdo Station

In conversations with McMurdo Station operators, regulatory constraints prohibit on-site disposal of waste. Given that emissions are allowable, as evidenced both by the plume from idling aircraft at Willy's Field and that the McMurdo Station is powered by fossil-fueled generators, it would be prudent to examine whether on-site disposal of certain wastes would be allowable if it were coupled with energy generation and extremely low emissions. Plasma Arc furnaces, advanced by scientists at the Georgia Tech, have demonstrated promise for waste disposal and modest energy generation. Candidate feedstocks for these furnaces include not only burnable waste, but also human waste. By gasifying and combusting significant portions of the waste and essentially vitrifying unburnable portions, the quantity of material that must be shipped from the station would be drastically reduced while producing energy at the same time.

Another contrast between McMurdo Station and Scott Base is the choice of vehicles. USAP, relying on GSA for fleet vehicles, is constrained to use what GSA offers and thus must use the oversized, overpowered, and low efficiency pickup trucks for runabouts. A dispassionate, objective study, which compared the operational costs of the current fleet with a fleet comprised of smaller, lighter, more efficient and the conventional vehicles, may provide an incentive for adoption of more efficient vehicles. At the very least, increased utilization of ATVs, where appropriate, would lead to increases in fleet efficiency while complying with GSA procurement rules.

A key element to assessing the future prospects for efficiency gains and investments in renewable energy systems lies with the staff energy management specialist. Unfortunately, the organizational constraints identified earlier make the task of implementation difficult for this position. Because of this, the most important function this individual can serve is to identify areas for potential savings or investment and to broadly propose a plan for analysis and implementation. By engaging outside experts that can concur with the energy manager and provide objectivity, the energy management expert can act as a catalyst for change.

In order for the energy management experts to perform their task in a way that is in accord with congressional intent, they should be adequately trained in energy assessment practices, adequately equipped with energy assessment tools and equipment, and should have familiarity with those that can provide objective support and analysis within and without the RPSC organization. Furthermore, because of the complexity of the site both structurally and organizationally, and because of the organizational, environmental and regulatory constraints, it is important that the energy management expert position experience low turnover. A long-term expert with historical appreciation for and understanding of existing equipment, buildings, and practices will be best suited to identify solutions that are likely to be adopted by the organization.

Finally, there is a wealth of environmental data for McMurdo Station, BITF, and Marble Point. Unfortunately, this data tends to be dispersed among numerous sites, organizations, and time. This factor adds to the difficulty for outside organizations to assess potential solutions as identified by the energy management expert. If this information were consolidated to a single database, the maintenance and interpretation of this data stream would be far easier for the energy management expert and thus proposals could be more readily considered by others.

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Appendix A - Conceptual 1-Line Electrical Schematics

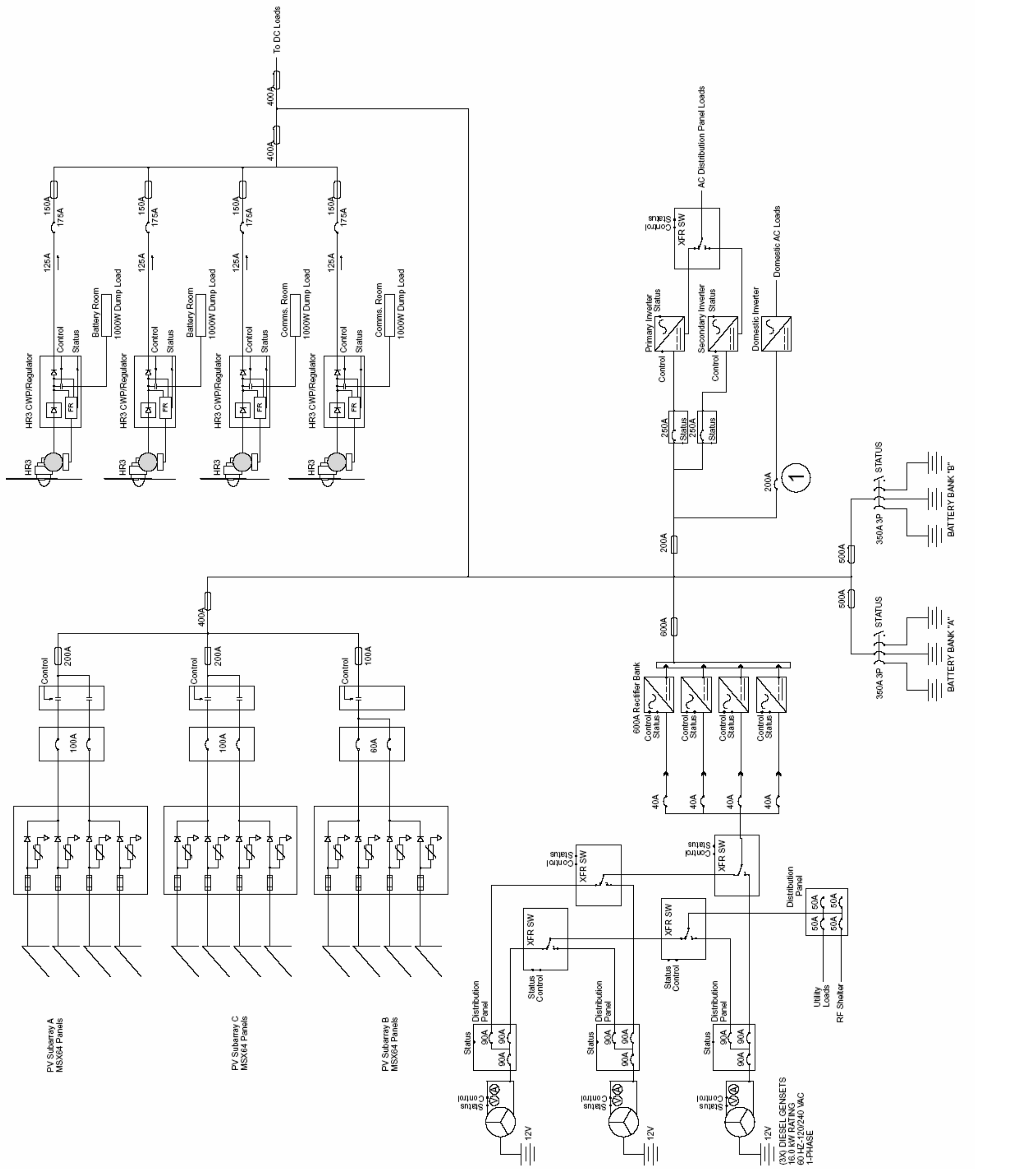

Figure A-1 – Baseline Electrical Schematic

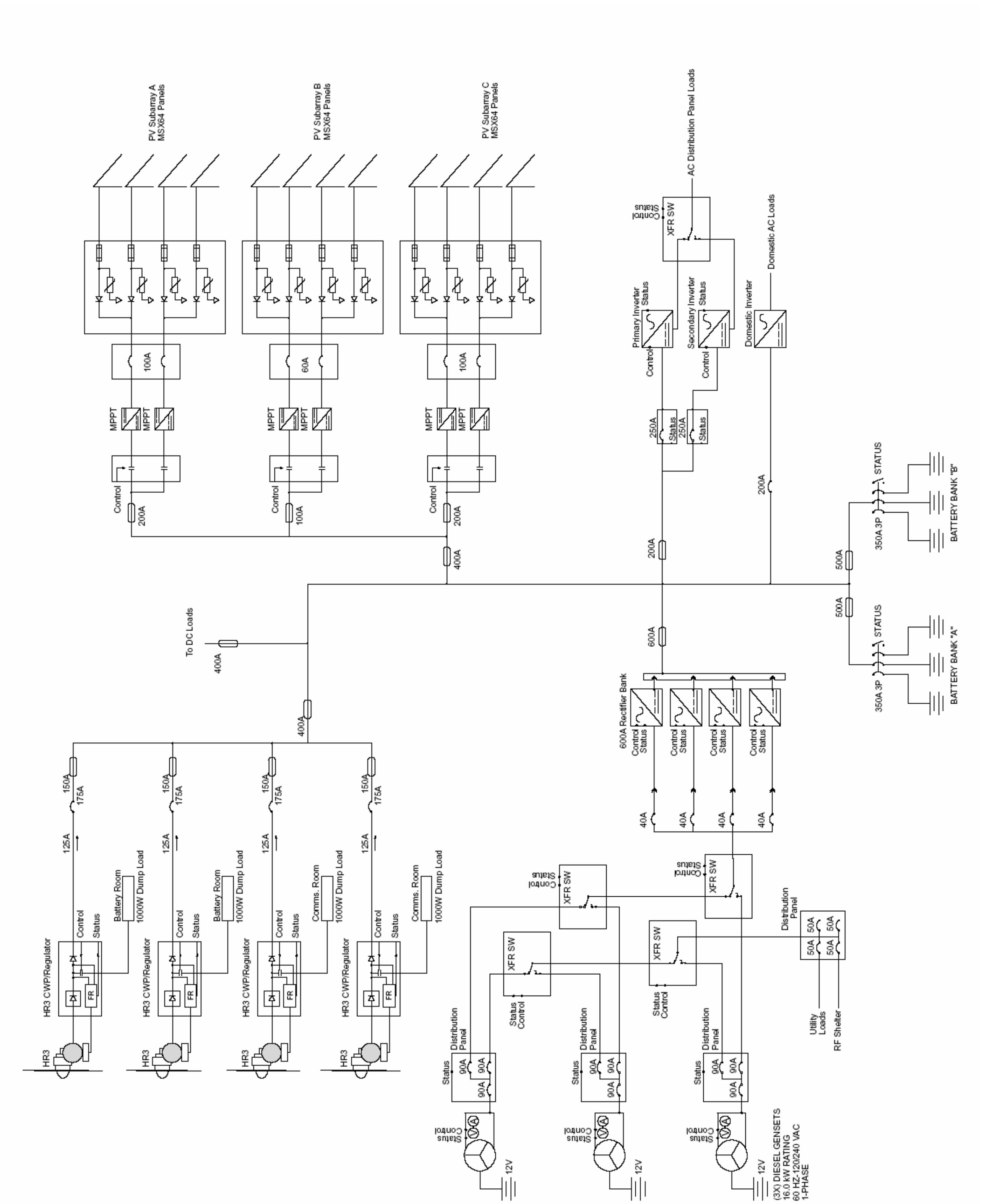

Figure A-2 – Preliminary 1-line Electrical Schematic for Minor Upgrades

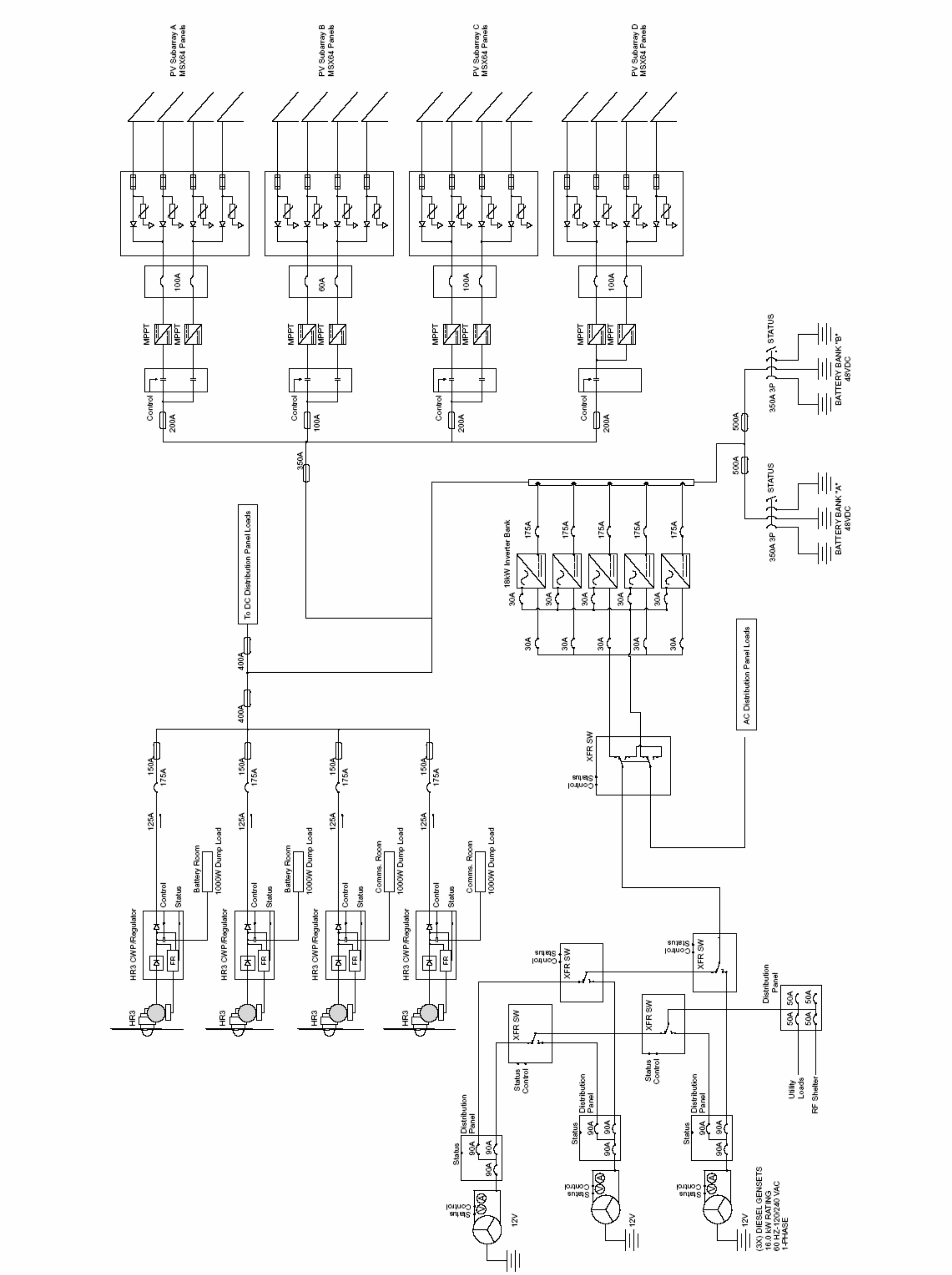

Figure A-3 - Preliminary 1-line Electrical Schematic for Significant Changes

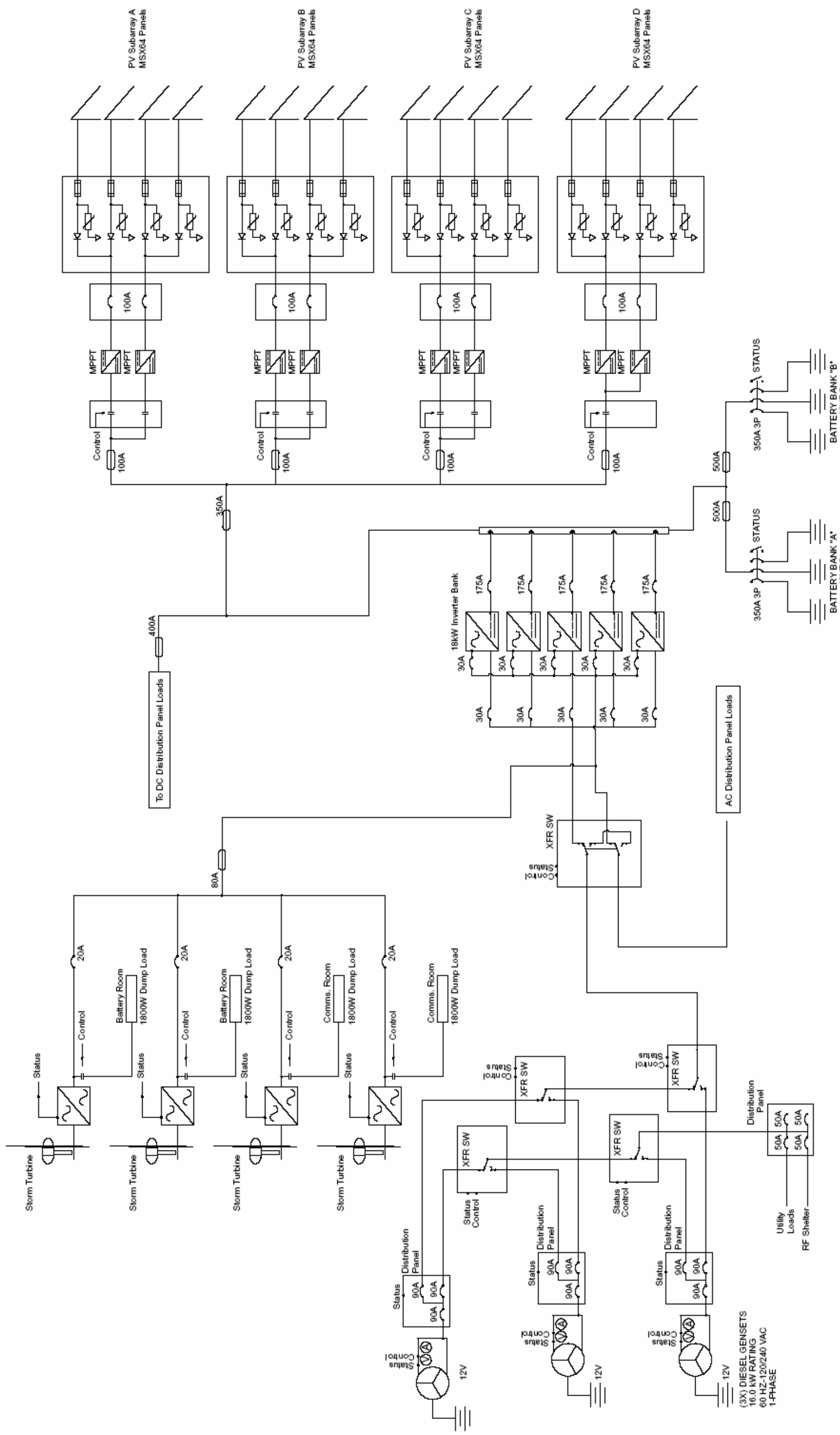

Figure A-4 - Preliminary 1-line Electrical Schematic for New System

Appendix B
Diesel and Fuel Run Time Logs
2003-2006

Fuel consumption for Black Island Telecommunications
Facility
Austral Summer 2003/2004, 2004/2005, 2005/2006

For week ending: 10/12/03 (First Report for 03/04)
Tank #1: 3572 gal (JP8)
Tank #2: 3572 gal (JP8)
Tank #3: 3572 gal (JP8)
Tank #4: 3572 gal (JP8)
Total Fuel on Site: 14288 gal. (JP8)

Yanmar Generator Engine Hours:
#1 – 02293 (2/16/03) #1 -03671 (10/12/03)
#2 – 12283 (2/16/03) #2 -14492 (10/12/03)
#3 – 08858 (2/16/03) #3 -10688 (10/12/03)

For week ending: 10/19/03
Tank #1: 3608 gal (JP8)
Tank #2: 3612gal (JP8)
Tank #3: 3610 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3610gal (JP8)
Total Fuel on Site: 14440 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 03671
#2: 14492
#3: 10836

For week ending: 10/26/03
Tank #1: 3420 gal (JP8)
Tank #2: 3420 gal (JP8)
Tank #3: 3420 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3420 gal (JP8)
Total Fuel on Site: 13680 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 03671
#2: 14528
#3: 10975

For week ending: 11/02/03
Tank #1: 3420 gal (JP8)
Tank #2: 3420 gal (JP8)

Tank #3: 3420 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3420 gal (JP8)
Total Fuel on Site: 13680 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 03677
#2: 14592
#3: 10975

For week ending: 11/09/03
Tank #1: 3504 gal (JP8)
Tank #2: 3444 gal (JP8)
Tank #3: 3534 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3753 gal (JP8)
Total Fuel on Site: 14235 gal. (JP8)**

Yanmar Generator Engine Hours:
#1: 03836
#2: 14593
#3: 11038

For week ending: 11/16/03
Tank #1: 3444 gal (JP8)
Tank #2: 3383 gal (JP8)
Tank #3: 3474 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3564 gal (JP8)
Total Fuel on Site: 13865 gal. (JP8)**

Yanmar Generator Engine Hours:
#1: 03931
#2: 14606
#3: 11108

For week ending: 11/23/03
Tank #1: 3444 gal (JP8)
Tank #2: 3353 gal (JP8)
Tank #3: 3474 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3564 gal (JP8)
Total Fuel on Site: 13835 gal. (JP8)**

Yanmar Generator Engine Hours:
#1: 03952
#2: 14630
#3: 11125

For week ending: 11/30/03
Tank #1: 3444 gal (JP8)
Tank #2: 3444 gal (JP8)

Tank #3: 3444 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3444 gal (JP8)
Total Fuel on Site: 13776 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 04014
#2: 14641
#3: 11136

For week ending: 12/07/03
Tank #1: 3353 gal (JP8)
Tank #2: 3280 gal (JP8)
Tank #3: 3383 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3504 gal (JP8)
Total Fuel on Site: 13520 gal. (JP8)**

Yanmar Generator Engine Hours:
#1: 04052
#2: 14692
#3: 11151

For week ending: 12/14/03
Tank #1: 3192 gal (JP8)
Tank #2: 3192 gal (JP8)
Tank #3: 3192 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3192 gal (JP8)
Total Fuel on Site: 12768 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 04057
#2: 14707
#3: 11151

For week ending: 12/21/03
Tank #1: 3353 gal (JP8)
Tank #2: 3197 gal (JP8)
Tank #3: 3322 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3414 gal (JP8)
Total Fuel on Site: 13286 gal. (JP8)**

Yanmar Generator Engine Hours:
#1: 04093
#2: 14759
#3: 11160

For week ending: 12/28/03
Tank #1: 3280 gal (JP8)
Tank #2: 3197 gal (JP8)

Tank #3: 3322 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3414 gal (JP8)
Total Fuel on Site: 13213 gal. (JP8)**

Yanmar Generator Engine Hours:
#1: 04100
#2: 14778
#3: 11196

For week ending: 12/28/03
Tank #1: 3280 gal (JP8)
Tank #2: 3197 gal (JP8)
Tank #3: 3322 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3414 gal (JP8)
Total Fuel on Site: 13213 gal. (JP8)**

Yanmar Generator Engine Hours:
#1: 04100
#2: 14778
#3: 11196

For week ending: 01/04/04
Tank #1: 3154 gal (JP8)
Tank #2: 3154 gal (JP8)
Tank #3: 3154 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3154 gal (JP8)
Total Fuel on Site: 12616 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 04134
#2: 14778
#3: 11206

For week ending: 01/11/04

Tank #1: 3239 gal (JP8)
Tank #2: 3134 gal (JP8)
Tank #3: 3239 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3353 gal (JP8)
Total Fuel on Site: 12965 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 04164
#2: 14807
#3: 11206

For week ending: 01/18/04
Tank #1: 3166 gal (JP8)

Tank #2: 3103 gal (JP8)
Tank #3: 3197 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3322 gal (JP8)
Total Fuel on Site: 12788 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 04188
#2: 14812
#3: 11241

For week ending: 01/25/04
Tank #1: 3134 gal (JP8)
Tank #2: 3071 gal (JP8)
Tank #3: 3197 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3301 gal (JP8)
Total Fuel on Site: 12703 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 04217
#2: 14812
#3: 11248

For week ending: 02/01/04
Tank #1: 3103 gal (JP8)
Tank #2: 3040 gal (JP8)
Tank #3: 3134 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3280 gal (JP8)
Total Fuel on Site: 12557 gal. (JP8)**

Yanmar Generator Engine Hours:
#1: 04241
#2: 14849
#3: 11301

For week ending: 02/08/04 (last weekly for 2003/2004)
Tank #1: 3071 gal (JP8)
Tank #2: 3008 gal (JP8)
Tank #3: 3134 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3239 gal (JP8)
Total Fuel on Site: 12452 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 04241
#2: 14873
#3: 11334

For week ending: 10/23/04 (first weekly for 2004/2005)
Tank #1: 3103 gal (JP8)
Tank #2: 2976 gal (JP8)

Tank #3: 3134 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3280 gal (JP8)
Total Fuel on Site: 12493 gal. (JP8) Temp: 1 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 05839
#2: 16129
#3: 12827

For week ending: 10/30/04
Tank #1: 3008 gal (JP8)
Tank #2: 2994 gal (JP8)
Tank #3: 3071 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3239 gal (JP8)
Total Fuel on Site: 12312 gal. (JP8) Temp: -3 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 05839
#2: 16226
#3: 12900

For week ending: 11/06/04
Tank #1: 2976 gal (JP8)
Tank #2: 2912 gal (JP8)
Tank #3: 3040 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3197 gal (JP8)
Total Fuel on Site: 12125 gal. (JP8) Temp: 13 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 05914
#2: 16299
#3: 12900

For week ending: 11/13/04
Tank #1: 2944 gal (JP8)
Tank #2: 2879 gal (JP8)
Tank #3: 3008 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 3166 gal (JP8)
Total Fuel on Site: 11997 gal. (JP8) Temp: 21 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 06076
#2: 16299
#3: 12900

For week ending: 11/20/04 through 12/04/04
Tank #1: 2815 gal (JP8)
Tank #2: 2750 gal (JP8)
Tank #3: 2876 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 2944 gal (JP8)
Total Fuel on Site: 11385 gal. (JP8) Temp: 27 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 06317 new engine
#2: 16412
#3: 13024

For week ending: 12/11/04
Tank #1: 2847 gal (JP8)
Tank #2: 2783 gal (JP8)
Tank #3: 2815 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 2944 gal (JP8)
Total Fuel on Site: 11389 gal. (JP8) Temp: 25 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 06317
#2: 16578
#3: 13034

For week ending: 12/18/04
Tank #1: 2750 gal (JP8)
Tank #2: 2718 gal (JP8)
Tank #3: 2847 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 2879 gal (JP8)
Total Fuel on Site: 11194 gal. (JP8) Temp: 31 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 06317
#2: 16642
#3: 13119

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Tank #1: 2718 gal (JP8)
Tank #2: 2686 gal (JP8)
Tank #3: 2815 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 2879 gal (JP8)
Total Fuel on Site: 11098 gal. (JP8) Temp: 31 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 06318

#2: 16647
#3: 13284

For week ending: 01/01/05
Tank #1: 2621 gal (JP8)
Tank #2: 2555 gal (JP8)
Tank #3: 2686 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 2847 gal (JP8)
Total Fuel on Site: 10709 gal. (JP8) Temp: 28 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 06318
#2: 16647
#3: 13432

For week ending: 01/08/05
Tank #1: 2588 gal (JP8)
Tank #2: 2555 gal (JP8)
Tank #3: 2686 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 2815 gal (JP8)
Total Fuel on Site: 10644 gal. (JP8) Temp: 30 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 06318
#2: 16760
#3: 13528

For week ending: 01/15/05
Tank #1: 2588 gal (JP8)
Tank #2: 2425 gal (JP8)
Tank #3: 2654 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 2686 gal (JP8)
Total Fuel on Site: 10353 gal. (JP8) Temp: 28 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 06386
#2: 16809
#3: 13543

For week ending: 01/22/05
Tank #1: 2555 gal (JP8)
Tank #2: 2425 gal (JP8)
Tank #3: 2686 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 2686 gal (JP8)
Total Fuel on Site: 10352 gal. (JP8) Temp: 18 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 06434
#2: 16821
#3: 13543

For week ending: 01/29/05
Tank #1: 2425 gal (JP8)
Tank #2: 2360 gal (JP8)
Tank #3: 2480 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 2621 gal (JP8)
Total Fuel on Site: 9886 gal. (JP8) Temp: 17 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 06436 PM
#2: 16823 PM
#3: 13559 PM

For week ending: 02/05/05 (last weekly for 2004/2005)
Tank #1: 2425 gal (JP8)
Tank #2: 2360 gal (JP8)
Tank #3: 2425 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: 2588 gal (JP8)
Total Fuel on Site: 9728 gal. (JP8) Temp: 19 degree Fahrenheit

Yanmar Generator Engine Hours:
#1: 06525
#2: 16914
#3: 13559

For week ending: 10/08/05 (first weekly for 2005/2006)
Tank #1: gal (JP8)
Tank #2: gal (JP8)
Tank #3: 3351 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)
Total Fuel on Site: 13404 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07412 2/11/05 through 10/08/05 887 hrs
#2: 17989 2/11/05 through 10/08/05 1072 hrs
#3: 15206 2/11/05 through 10/08/05 1638 hrs

For week ending: 10/15/05
Tank #1: gal (JP8)
Tank #2: gal (JP8)
Tank #3: 3344 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)

Total Fuel on Site: 13376 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07413
#2: 18095
#3: 15260

For week ending: 10/22/05
Tank #1: gal (JP8)
Tank #2: gal (JP8)
Tank #3: 3306 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)
Total Fuel on Site: 13224 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07502
#2: 18162
#3: 15272

For week ending: 10/29/05
Tank #1: gal (JP8)
Tank #2: gal (JP8)
Tank #3: 3302 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)
Total Fuel on Site: 13208 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07504
#2: 18211
#3: 15389

For week ending: 11/05/05
Tank #1: gal (JP8)
Tank #2: gal (JP8)
Tank #3: 3306 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)
Total Fuel on Site: 13224 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07504
#2: 18211
#3: 15558

For week ending: 11/12/05
Tank #1: gal (JP8)
Tank #2: gal (JP8)
Tank #3: 3192 gal (JP8) {Radar Fuel Sensor attached to #3}

Tank #4: gal (JP8)
Total Fuel on Site: 12768 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07671
#2: 18211
#3: 15558

For week ending: 11/19/05
Tank #1: gal (JP8)
Tank #2: gal (JP8)
Tank #3: 3116 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)
Total Fuel on Site: 12464 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07837
#2: 18211
#3: 15558

For week ending: 11/26/05
Tank #1: gal (JP8)
Tank #2: gal (JP8)
Tank #3: 3040 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)
Total Fuel on Site: 12160 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07837
#2: 18252
#3: 15559

For week ending: 12/03/05
Tank #1: gal (JP8)
Tank #2: gal (JP8)
Tank #3: 3002 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)
Total Fuel on Site: 12008 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07837
#2: 18414
#3: 15628

For week ending: 12/10/05
Tank #1: gal (JP8)
Tank #2: gal (JP8)

Tank #3: 3002 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)
Total Fuel on Site: 12008 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07837
#2: 18435
#3: 15635

For week ending: 12/17/05
Tank #1: gal (JP8)
Tank #2: gal (JP8)
Tank #3: 3078 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)
Total Fuel on Site: 12312 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07837 PM due 07661
#2: 18435 PM due 18121
#3: 15635 PM due 15330

For week ending: 12/24/05
Tank #1: gal (JP8)
Tank #2: gal (JP8)
Tank #3: 2964 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)
Total Fuel on Site: 11856 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07837 PM due 07661
#2: 18436 PM due 18121
#3: 15714 PM due 15330

For week ending: 12/31/05
Tank #1: gal (JP8)
Tank #2: gal (JP8)
Tank #3: 2964 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)
Total Fuel on Site: 11856 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07837 PM due 07661
#2: 18448 PM due 18121
#3: 15793 PM due 15330

For week ending: 01/07/06
Tank #1: gal (JP8)

Tank #2: gal (JP8)
Tank #3: 2961 gal (JP8) {Radar Fuel Sensor attached to #3}
Tank #4: gal (JP8)
Total Fuel on Site: 11844 gal. (JP8)

Yanmar Generator Engine Hours:
#1: 07837 PM due 07661
#2: 18556 PM due 18121
#3: 15793 PM due 15330

Appendix C – Overview of PLC Control

1. The PLC monitors power sources to maintain the batteries at safe voltage levels and supply power to interconnected loads. Redundant power sources include Wind Turbine Generators (WTGs), active Photovoltaic (PV) arrays, and diesel powered Generator Sets (GenSets). The diesel GenSets provide DC power through rectifiers to charge the battery banks.
2. The PLC is programmed to protect the DC bus from excessive current. If total generated source amps exceed 950A, PVB is opened, and will not reconnect until the current drops below 700 A.

Wind Turbine Generators

1. The output voltages of the four wind turbines are self-regulating. Therefore, the PLC does not need to control their operation to ensure the bus voltage stays within tolerance. With regards to the WTGs, the PLC only monitors the "VOLTAGE AVAILABLE" signal to determine if wind power is available to power the dump loads.
2. If the batteries are sufficiently charged and the PLC determines that a particular room requires more heat, the wind turbines can provide heat to the room via their dump loads. The following summarizes the control of the four dump loads:
3. Dump Load 1:
   Dump load 1 is located on the east wall of the Battery Room. Dump load 1 is enabled only when all of the following conditions are met:
   - Voltage buildup on WTG 1
   - Battery voltage > 25V DC
   - Battery Room temperature < 60°F
4. Dump load 1 is disabled if any of the following conditions occur:
   - No voltage buildup on WTG 1
   - Battery voltage < 24V DC
   - Battery Room temperature > 70°F
5. Dump Load 2:
   Dump load 2 is located on the west wall of the Communications Room. Dump load 2 is enabled if all of the following conditions are met:
   - Voltage buildup on WTG 2
   - Battery voltage > 25V DC
   - Communications Room temperature < 60°F
6. Dump load 2 is disabled if <u>any</u> of the following conditions are true:
   - No voltage buildup on WTG 2
   - Battery voltage < 24V DC
   - Communications Room temperature > 70°F
7. Dump Load 3:
   Dump load 3 is located on the north wall of the Communications Room. Dump load 3 is enabled if <u>all</u> of the following conditions are met:
   - Voltage buildup on WTG 3
   - Battery voltage > 25V DC
   - Communications Room temperature < 60°F
8. Dump load 3 is disabled if <u>any</u> of the following conditions are true:
   - No voltage buildup on WTG 3
   - Battery voltage < 24V DC
   - Communications Room temperature > 70°F
9. Dump Load 4:
   Dump load 4 is located on the south wall of the Battery Room. Dump load 4 is enabled if all of the following conditions are met:
   - Voltage buildup on WTG 4

- Battery voltage > 25V DC
- Battery Room temperature < 60°F

10. Dump load 4 is disabled if any of the following conditions are true:
    - No voltage buildup on WTG 4
    - Battery voltage < 24V DC
    - Battery Room temperature > 70°F

PV Arrays

3. Photovoltaics (PVs) supporting Black Island consist of arrays A & B, which have separate controllable disconnects from the batteries. The PVs are controlled by three set points, (HI+, HI, and LO) that the PLC compares with the bus voltage. If the battery voltage exceeds the HI+ limit value or the HI limit for a given time period, the PVs are disconnected. The bus voltage must fall below the LO setting before reconnecting PV voltage to the batteries. More specifically, PV array control is defined as follows:

1. For PVA Control:
   - IF ((Vbatt >= PVA HI+) OR 29.4V) FOR 1 second, then OPEN PVA DISCONNECT
   - IF ((Vbatt >= PVA HI) & PVB IS OPEN FOR 30 seconds, then OPEN PVA DISCONNECT
   - IF ((Vbatt <= PVA LO) AND 28.4V) FOR 60 seconds, then CLOSE PVA DISCONNECT
2. For PVB Control:
   - IF ((Vbatt >= PVB HI+) OR 29.4V) FOR 1 seconds, then OPEN PVB DISCONNECT
   - IF ((Vbatt >= PVB HI) OR 29.3V) FOR 30 seconds, then OPEN PVB DISCONNECT
   - IF ((Vbatt <= PVB LO) AND 28.7V) FOR 60 seconds, then CLOSE PVB DISCONNECT
3. At 25°C, the set points for the PV arrays are as such.
   - PVA HI+ - 29.4V -
   - PVA HI - 28.8V
   - PVA LO - 28.2V
   - PVB HI+ - 29.4V -
   - PVB HI - 28.6V
   - PVB LO - 28.0V

   Slight adjustments are made from these set points to compensate for lower or higher battery bank temperatures (set points are shifted down as the battery temperature increases).
5. PV Low Power Output Disconnect

   If the PV current output is less than 1% of rated for 1 hour, then PVA and PVB are disconnected and enter "low power shutdown." After the PVs have been in "low power shutdown" for one hour, they are reconnected. If the PVs begin producing power within 5 minutes, and the bus voltage is below the PV LO set points, then the PVs are reconnected and are no longer considered in "low power shutdown." If the 5 minutes pass and less than 1% of the rated output is produced, the PVs enter "low power shutdown" for another hour until they retest.

Diesel Generator Control

1) There are three 16kW diesel generator sets, referred to as GenSet1, GenSet2, and GenSet3. Each generator set can perform any of the tasks listed below. In order to equalize regular use, GenSets are tasked in sequence to run intermittently. Technicians may lock-out any installed GenSet through WonderWare to prevent injury during maintenance, for instance. The GenSet will be shutdown if running and not allowed to start until enabled, again through WonderWare. With the lockout removed, the GenSet returns to the regular series.

Batteries

2) The PLC monitors battery voltage to assure that voltage levels remain within safe tolerances for the batteries and the devices connected to the system bus.

Load Management

3) The controller keeps the highest priority loads on-line as long as possible in situations of low power. In situations where the battery capacity is dropping the controller disconnects the lowest priority loads first, to assure the highest priority loads remain connected. The highest priority loads are the last to be taken off-line, only after battery voltage declines below the lowest set point. The loads are divided into three different prioritized levels:
   - Priority 3 — Lowest Priority (first load dropped)
   - Priority 2 — Medium Priority (intermediate loads dropped, essential to maintain service)
   - Priority 1 — Highest Priority (primary systems, last dropped)

1. Priority 3 Disconnect
   - Priority 3 loads are dropped when voltage falls below 22.8V DC.
2. Priority 2 Disconnect
   - If the battery voltage continues its decline and is < 22.2 VDC and still > 21.6 VDC, the Priority 2 loads are dropped.
3. Priority 1 Disconnect
   - If the battery voltage continues its decline and is < 21.6 VDC, the Priority 1 loads are dropped.
4. Priority 1 Reconnection
   - With the battery voltage on the rise and > 22.6 VDC and still < 23.2 VDC, the Priority 1 loads are reinstated.
5. Priority 2 Reconnect
   - With the battery voltage on the rise and > 23.2 VDC and still < 23.8 VDC, the Priority 2 loads are reinstated.
6. Priority 3 Reconnect
   - With the battery voltage on the rise and > 23.8V DC, the Priority 3 loads are reinstated.

Appendix D– Sample Product Specifications

MX60 MPPT Charge Controller

The MX60 raises the bar for high performance solar controllers. OutBack's ingenuity and engineering experience has been combined to maximize the output power of your expensive solar array. Our real time active Maximum Power Point Tracking (MPPT) system ensures that your solar array is operating at its peak power point regardless of age, shading or environmental conditions. Systems with large solar arrays are now a snap thanks to the MX60's 60 amp DC output current rating for 12, 24 or 48 VDC systems - all with just one product model!

Real wiring flexibility of your solar array is finally here because of the MX60's wide range DC input, up to 150 VOC. The ability to step-down a high voltage solar array to a low voltage battery can save you money by reducing the size of wire required and making the installation simpler and faster. Our smart multistage recharging process ensures your batteries are recharged efficiently and gently to prolong battery life and achieves the highest possible performance.

All of the MX60's status information is displayed on the large built-in 3.1" (8 cm) backlit LCD screen. Monitoring your solar array's performance is easy because of included data logging system that automatically records the last 64 days of system operation. OutBack's network communication system allows your MX60 to communicate with the rest of your OutBack system, eliminating multiple product interaction problems and allowing remote monitoring via the OutBack MATE display up to 1000 feet / 300 meters away.

MX60 Specifications Specifications

Read about the OutBack battery charging technique Here

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Arlington WA, 98223
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Comments? email the webmaster

MX60

Maximum Power Point Tracking Charge Controller

OutBack Power Systems

- Active Maximum Power Point Tracking
- High Operating Efficiency
- Battery Voltages from 12 VDC to 60 VDC
- PV Arrays up to 150 VDC Open Circuit
- Negative or Positive Ground Systems
- Built-in Data Logging
- Standard 2 Year Warranty

The MX60 is on the cutting edge of charge controller design. OutBack's real time active Maximum Power Point Tracking (MPPT) system ensures that your solar array is operating at its peak power point regardless of age, shading or environmental conditions. A peak operating efficiency of 98% maximizes your PV array's performance. The MX60's wide DC input range and 60 amp DC output current rating for 12, 24 or 48 VDC systems provides unmatched flexibility in the wiring as well as the sizing of your solar array. The ability to step-down a high voltage solar array to a low voltage battery can save you money by reducing the size of wire required and making the installation simpler and faster.

All of the MX60's status information is displayed on the large built-in 3.1" (8 cm) backlit LCD screen and OutBack's exclusive system networking allows your MX60 to communicate with the rest of your OutBack products for complete integration and high performance operation. Monitoring the performance of your solar array investment is easy through the use of the built-in data logging system or via the MATE and optional PC software (available separately).

The MX60 is the only choice when you demand a high performance, efficient and customizable charge controller for your advanced power system.

MX60 Specifications

Nominal Battery Voltages		12, 24, 32, 36, 48, 54 or 60 VDC (Single model - selectable via field programming)
Output Current		60 amps maximum with adjustable current limit for smaller systems
Maximum Solar Array Size		12VDC systems 800 Watts / 24 VDC systems 1600 Watts / 48 VDC systems 3200 Watts
PV Open Circuit Voltage (VOC)		150 VDC absolute maximum coldest conditions / 140 VDC start-up and operating maximum
Standby Power Consumption		Less than 1 Watt
Charging Regulation		Five Stages: Bulk, Absorption, Float, Silent and Equalization
Voltage Regulation Set points		10 to 80VDC user adjustable with password protection
Equalization Voltage		Up to 5.0 VDC above Absorb Set point Adjustable Timer - Automatic Termination when completed
Battery Temperature Compensation		Automatic with optional RTS installed / 5.0 mV per °C per 2V battery cell
Voltage Step-Down Capability		Can charge a lower voltage battery from a higher voltage PV array
Power Conversion Efficiency	Typical	98% at 60 amps with a 48 V battery and nominal 48 V solar array
Status Display		3.1" (8 cm) backlit LCD screen with 4 lines with 80 alphanumeric characters total
Remote Interface		Proprietary network system using RJ 45 Modular Connectors with CAT 5e Cable (8 wires)
Data Logging		Last 64 days of operation - amp hours, watt hours and time in float for each day along with total accumulated
		amp hours, kW hours of production
Hydro / Wind Turbine Applications		Consult factory for approved turbines
Positive Ground Applications		Requires two pole breakers for switching both positive and negative conductors on both solar array
		and battery connections (HUB-4 and HUB-10 are not recommended for use in positive ground applications)
Operating Temperature Range		Minimum -40° to maximum 60° C (Power capacity of the controller is derated when above 25°C)
Environmental Rating		Indoor Type 1
Conduit Knockouts		Two ½" and ¾" on the back; One ¾" and 1" on each side; Two ¾" and 1" on the bottom
Warranty		Standard 2 year / Optional 5 year
Weight	Unit	11.6 lbs (5.3 kg)
	Shipping	14 lbs (6.4 kg)
Dimensions (H x W x L)	Unit	13.5 x 5.75 x 4" (40 x 14 x 10 cm)
	Shipping	18 x 11 x 8" (46 x 30 x 20 cm)
Options		Remote Temperature Sensor (RTS), HUB and MATE

OutBack Power Systems

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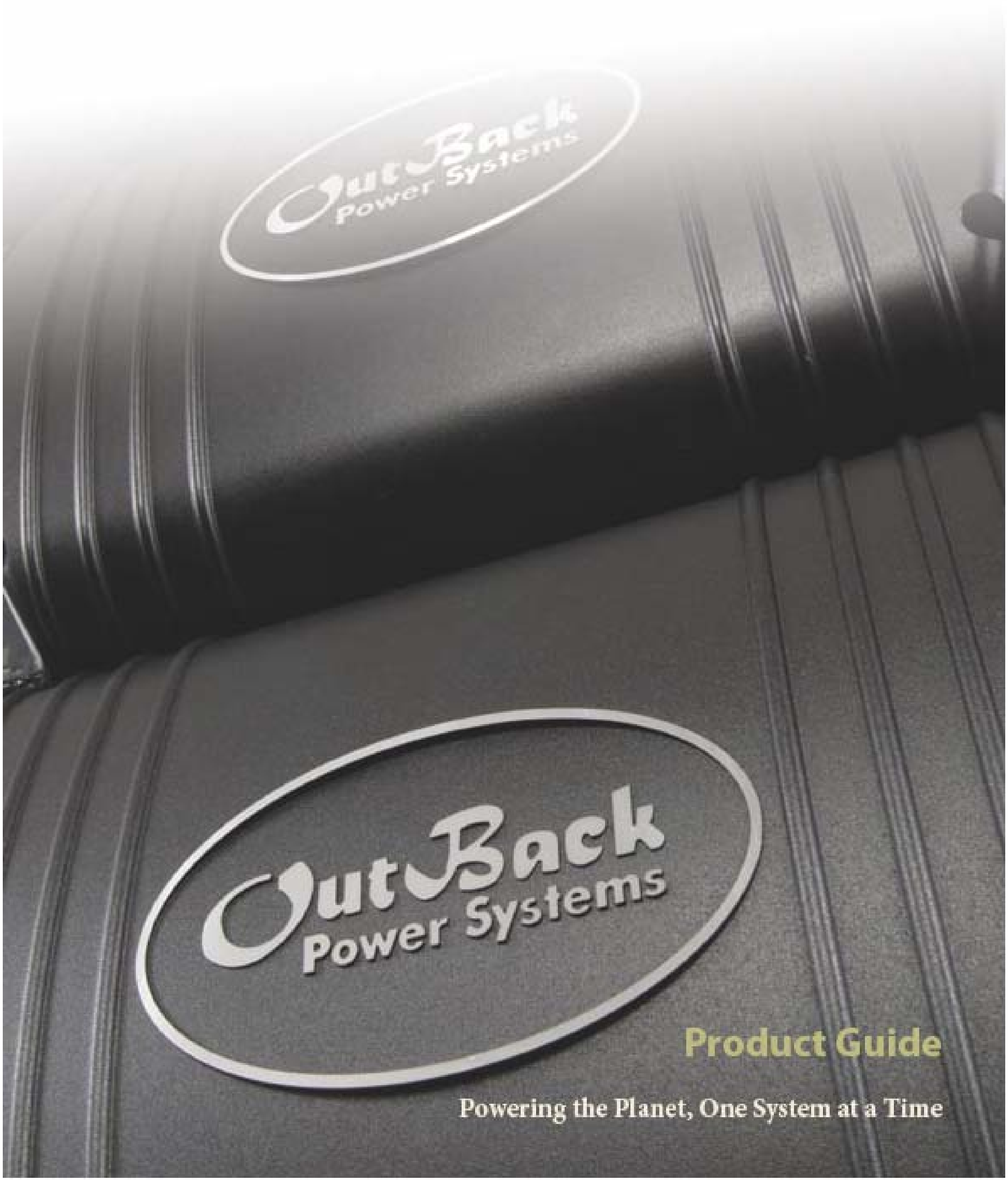
Available From:

OutBack Power Systems



Welcome

Welcome to the fifth year of OutBack Power designing and manufacturing great products with you, our customers, in mind. OutBack's ability to continuously innovate and lead the industry as well as listen to our customers has been a major influence in our success.

Since our last catalog, OutBack has spent countless hours in research and development to engineer products at an elevated level of technological innovation. Our efforts have resulted in new products and improved reliability. Some of these new products include: our vented higher power versions of our inverter/chargers, the world's most efficient grid-interactive inverter/charger, a fully integrated grid-interactive system and mobile inverter/chargers for when you are on the move.

Despite our accomplishments we will not become complacent. In 2005 we expect to maintain a steady growth and pioneer solutions to challenging problems and developing even more cutting edge power electronics. We will continue to collaborate with our customers in order to develop our products and improve our industry leading technical support.

We are confident that OutBack is a company that is built to last, and we would like to thank you for your continued support in powering the planet, one system at a time...

History

2001 OutBack Power started by a passionate group of engineers whom wanted to bring power conversion electronics technology into the 21st century.

This small startup quickly grew by offering innovative and well designed solutions to renewable energy problems. OutBack listened to their customers and made many of the changes that were suggested, creating a truly customer focused company in the power conversion electronics industry.

2002 OutBack introduces its first sealed sinewave inverter/charger - the FX2024, with resounding success.

This single model changed the way people looked at system design by offering unprecedented flexibility in system design and expansion while the sealed construction allowed for uses which previously would have been considered too "extreme" for other inverter/chargers.

OutBack releases the MX60 solar MPPT charge controller redefining performance and value.

This revolutionary product changed the way solar systems were being installed and quickly gained a reputation for getting the most power possible from a PV array - often making it more expensive to not use one.

2003 OutBack launches the first of the vented versions of the FX series inverter/chargers.

These VFX models were introduced in direct response to our customer's requests providing higher power at a similar price as the sealed counterpart.

OutBack launches the PS2 value - priced system integration accessories.

This line of accessories addressed the needs of our customers for competitively priced system integration accessories for smaller systems.

2004 OutBack releases the world's most efficient grid-interactive inverter/charger.

These models raise the bar for performance and value for battery-connected grid-interactive inverter/charger systems. OutBack introduces the PS1 fully integrated grid-interactive power system.

This unique system sets a new standard for system integration, performance and ease of installation in grid-interactive applications.

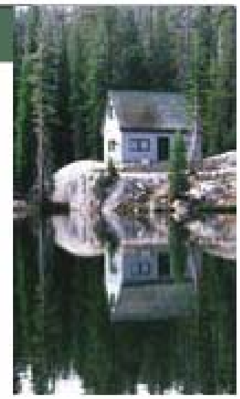
2005 What's new at OutBack? Read these pages to find out...

Index

Design by Karen O'Bryan
Photography by Erik Stuhaug

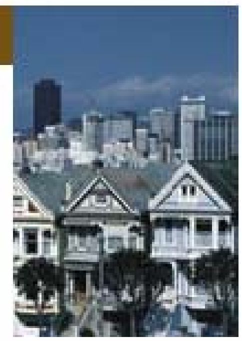
Off-Grid

Solar. Wind. Hydro. Generator. No matter what your energy source OutBack's products are engineered to provide your home or business with reliable electricity day-in and day-out. The OutBack modular system architecture allows your system to grow along with your power needs up to 36,000 watts. Power hungry appliances like washing machines, air conditioning and power tools are easily started by our inverter's substantial surge power capability. When not being used, the inverter enters a power save mode, which consumes as little as 3 watts, saving your battery power for when you need it the most. OutBack's innovative Maximum Power Point Tracking (MPPT) technology gets the most from your solar array or can also control hydro or wind turbine charging sources. Complete system status and control is easily monitored by a single control, instead of requiring the user to keep an eye on multiple displays and status indicators.



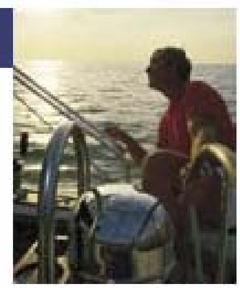
Grid-Interactive

Grid-Interactive renewable energy systems enable you to demonstrate your personal commitment to a renewable energy future. With the OutBack grid-interactive system, backup AC power is made available 24 hours a day in the event of a utility outage, providing reliable power and peace-of-mind. At night, the inverter's automatic power save mode ensures that energy is not wasted by needlessly charging your batteries from the utility grid. An average conversion efficiency of 91% using the California Energy Commission (CEC) test protocol provides greater savings and a shorter time period for system payback. OutBack's grid-interactive technology provides you more than a typical solar inverter, we also have an unmatched ability to utilize solar, wind and hydropower sources.



Mobile and Marine

OutBack's Mobile and Marine inverter/charger models provide the high performance and reliability you need no matter where your travels take you. Our die-cast metal construction allows mounting in any position, even upside down. The required AC input neutral/ground switching is taken care of by a fully integrated 30 amp AC transfer switch for shore chord or generator hook-up. Three circuit boards and a simple design make field servicing the unit easy no matter where you are. Rigorous testing at the factory ensures that each inverter/charger works the first time as well as for many years to come.



European and Exports

Wherever you are in the world, OutBack's European and Export off-grid inverter/chargers are engineered to provide your home or business with reliable 50 Hz AC power. Our high surge power capability starts the most demanding of 230 volt appliances and the modular system architecture makes expanding a system's power capacity or switching to three-phase output power simple and trouble free. Both sealed (FX) and vented (VFX) models are available with 50 Hz output to match your installation's environmental conditions. The inverter/chargers low weight (as low as 27 kilograms) and compact dimensions allow easy transport and installation in less than ideal locations. Our field serviceable design eliminates the need to ship inverters if repair or upgrades are required. Superior technical support is available from our European office, allowing questions to be promptly answered and any problems to be quickly resolved.

Sinewave Inverter/Charger

OutBack inverter/chargers are the next generation in advanced power management. Each is a DC to AC sinewave inverter, battery charger and AC transfer switch housed within a tough die-cast aluminum chassis.

Just like the local utility grid, the inverter produces true sinewave AC electricity for your stand-alone or backup power needs. Computers, TVs and pumps are just some of the examples of modern electronics that last longer and run better when powered with true sinewave electricity from an OutBack inverter. Starting up your air conditioning, washing machine or well pump is worry-free because of our high surge power capability.

Batteries and generators are the costly consumables when using inverters to generate electricity. The integrated smart battery charger uses multiple stages to perform quick recharging while prolonging battery life, saving your batteries and generator from unnecessary wear. Automatic switching between AC power sources is seamless due to an AC transfer switch that reacts in less than 16 milliseconds.

Unique networked communication is built into all OutBack products providing complete integration. Expanding your system with your growing power needs is as simple as adding additional inverters with modular architecture. Further flexibility is provided with the ability to be connected at any time in either parallel, series or three-phase power configurations. Industry leading OutBack reliability is achieved through simplified design and rugged construction.

FX

Sealed Inverter/Chargers

The FX series is designed to survive in environments that would normally destroy other inverter/chargers. Protection for internal components is provided by our die-cast aluminum chassis with a powder coated finish to prevent corrosion. Internal and external cooling fins allow for passive heat transfer, enabling peak operating efficiencies as high as 93% and looking cool while doing it. Water and small particles are kept out through the generous use of gaskets and 0-ring seals on all seams and openings. A protective conformal coating on all circuit boards provides the final line of defense against corrosion. The now standard externally mounted "TURBO" cooling system improves performance in hot conditions.

VFX

Vented Inverter/Chargers

The VFX series is designed for more protected installations. By utilizing an efficient active cooling design, the VFX models are available with AC output up to 3.6 kilowatts. Our tough die-cast aluminum chassis physically protects the internal components while the air intake includes an easily cleaned filter, which allows for ventilation while also keeping bugs and other debris out. All circuit boards are conformal coated to prevent corrosion from airborne moisture in humid conditions. The now standard DC wiring cover (DCC) protects the DC terminals and battery cables from damage.

Off-Grid Specifications

		Sealed Models			*Vented Models*		
		FX2012T	**FX2524T**	**FX3048T**	**VFX2812**	**VFX3524**	**VFX3648**
Nominal DC Input Voltage		12 VDC	24 VDC	48 VDC	12 VDC	24 VDC	48 VDC
Continuous Power Rating at 25° C		2000 VA	2500 VA	3000 VA	2800 VA	3500 VA	3600 VA
AC Voltage/Frequency		120 VAC 60 Hz	120 VAC 60 Hz	120 VAC 60 Hz	120 VAC 60 Hz	120 VAC 60 Hz	120 VAC 60 Hz
Continuous AC RMS Output at 25° C		17.0 amps AC	20.8 amps AC	25.0 amps AC	23.3 amps AC	29.2 amps AC	30.0 amps AC
Idle Power	Full	~ 20 Watts	~ 20 Watts	~ 23 Watts	~ 20 Watts	~ 20 Watts	~ 23 Watts
	Search	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts
Typical Efficiency		90%	92%	93%	90%	92%	93%
Total Harmonic Distortion	Typical	2%	2%	2%	2%	2%	2%
	Maximum	5%	5%	5%	5%	5%	5%
Output Voltage Regulation		± 2%	± 2%	± 2%	± 2%	± 2%	± 2%
Maximum Output Current	Peak	56 amps AC	70 amps AC	70 amps AC	56 amps AC	70 amps AC	70 amps AC
	RMS	40 amps AC	50 amps AC	50 amps AC	40 amps AC	50 amps AC	50 amps AC
AC Overload Capability	Surge	4800 VA	6000 VA	6000 VA	4800 VA	6000 VA	6000 VA
	5 Second	4000 VA	4800 VA	4800 VA	4000 VA	5000 VA	5000 VA
	30 Minutes	2500 VA	3200 VA	3200 VA	3200 VA	4000 VA	4000 VA
AC Input Current Maximum		60 amps AC	60 amps AC	60 amps AC	60 amps AC	60 amps AC	60 amps AC
AC Input Voltage Range (MATE Adjustable)		80 to 150 VAC	80 to 150 VAC	80 to 150 VAC	80 to 150 VAC	80 to 150 VAC	80 to 150 VAC
AC Input Frequency Range		54 to 66 Hz	54 to 66 Hz	54 to 66 Hz	54 to 66 Hz	54 to 66 Hz	54 to 66 Hz
DC Input Voltage Range		10.5 to 17.5 VDC	21.0 to 34.0 VDC	42.0 to 68.0 VDC	10.5 to 17.0 VDC	21.0 to 34.0 VDC	42.0 to 68.0 VDC
Continuous Battery Charge Output		80 amps DC	55 amps DC	35 amps DC	125 amps DC	85 amps DC	45 amps DC
Minimum Recommended DC Breaker		OBDC-250	OBDC-175	OBDC-100	OBDC-250	OBDC-250	OBDC-175
Warranty			Standard 2 year / Optional 5 year			Standard 2 year / Optional 5 year	
Weight	Unit		62.6 lbs (28.4 kg)			61 lbs (27.7 kg)	
	Shipping		67 lbs (30 kg)			64 lbs (29 kg)	
Dimensions (H x W x L)	Unit		13 x 8.25 x 16.25" (33 x 21 x 41 cm)			12 x 8.25 x 16.25" (30 x 21 x 41 cm)	
	Shipping		21.75 x 13 x 22" (55 x 33 x 56 cm)			21.75 x 13 x 22" (55 x 33 x 56 cm)	

Grid-Interactive Specifications

		Sealed Models		*Vented Models*	
		GTFX2524	**GTFX3048**	**GVFX3524**	**GVFX3648**
Nominal DC Input Voltage		24 VDC	48 VDC	24 VDC	48 VDC
Continuous Power Rating at 25° C		2500 VA	3000 VA	3500 VA	3600 VA
AC Voltage/Frequency		120 VAC 60 Hz	120 VAC 60 Hz	120 VAC 60 Hz	120 VAC 60 Hz
Continuous AC RMS Output at 25° C		20.8 amps AC	25.0 amps AC	29.2 amps AC	30.0 amps AC
Idle Power	Full	~ 20 Watts	~ 20 Watts	~ 20 Watts	~ 20 Watts
	Search	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts
Typical Efficiency		92%	93%	92%	93%
Total Harmonic Distortion	Inverting	2%	2%	2%	2%
	Selling	< 5%	< 5%	< 5%	< 5%
Output Voltage Regulation		± 2%	± 2%	± 2%	± 2%
Maximum Output Current	Peak	70 amps AC	70 amps AC	70 amps AC	70 amps AC
	RMS	50 amps AC	50 amps AC	50 amps AC	50 amps AC
AC Overload Capability	Surge	6000 VA	6000 VA	6000 VA	6000 VA
	5 Second	4800 VA	4800 VA	5000 VA	5000 VA
	30 Minutes	3200 VA	3200 VA	4000 VA	4000 VA
AC Input Current Maximum		60 amps AC	60 amps AC	60 amps AC	60 amps AC
AC Input Voltage Range (MATE Adjustable)		80 to 150 VAC	80 to 150 VAC	80 to 150 VAC	80 to 150 VAC
AC Input Frequency Range		58 to 62 Hz	58 to 62 Hz	58 to 62 Hz	58 to 62 Hz
DC Input Range		21.0 to 34.0 VDC	42.0 to 68.0 VDC	21.0 to 34.0 VDC	42.0 to 68.0 VDC
Continuous Battery Charge Output		55 amps DC	35 amps DC	85 amps DC	45 amps DC
Minimum Recommended DC Breaker		OBDC-175	OBDC-100	OBDC-250	OBDC-175
Warranty		Standard 2 year / Optional 5 year		Standard 2 year / Optional 5 year	
Weight	Unit	62.6 lbs (28.4 kg)		61 lbs (27.7 kg)	
	Shipping	67 lbs (30 kg)		64 lbs (29 kg)	
Dimensions (H x W x L)	Unit	13 x 8.25 x 16.25" (33 x 21 x 41 cm)		12 x 8.25 x 16.25" (30 x 21 x 41 cm)	
	Shipping	21.75 x 13 x 22" (55 x 33 x 56 cm)		21.75 x 13 x 22" (55 x 33 x 56 cm)	

Mobile Specifications

		Sealed Models			*Vented Models*		
		FX2012MT	**FX2524MT**	**FX2532MT**	**VFX2812M**	**VFX3524M**	**VFX3232M**
Nominal DC Input Voltage		12 VDC	24 VDC	32 VDC	12 VDC	24 VDC	32 VDC
Continuous Power Rating at 25° C		2000 VA	2500 VA	2500 VA	2800 VA	3500 VA	3200 VA
AC Voltage/Frequency		120 VAC 60 Hz	120 VAC 60 Hz	120 VAC 60 Hz	120 VAC 60 Hz	120 VAC 60 Hz	120 VAC 60 Hz
Continuous AC RMS Output at 25° C		17.0 amps AC	20.8 amps AC	20.8 amps AC	23.3 amps AC	29.2 amps AC	26.6 amps AC
Idle Power	Full	~ 20 Watts	~ 20 Watts	~ 21 Watts	~ 20 Watts	~ 20 Watts	~ 21 Watts
	Search	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts
Typical Efficiency		90%	92%	92%	90%	92%	92%
Total Harmonic Distortion	Typical	2%	2%	2%	2%	2%	2%
	Maximum	5%	5%	5%	5%	5%	5%
Output Voltage Regulation		± 2%	± 2%	± 2%	± 2%	± 2%	± 2%
Maximum Output Current	Peak	56 amps AC	70 amps AC	56 amps AC	56 amps AC	70 amps AC	56 amps AC
	RMS	40 amps AC	50 amps AC	40 amps AC	40 amps AC	50 amps AC	40 amps AC
AC Overload Capability	Surge	4800 VA	6000 VA	4800 VA	4800 VA	6000 VA	4800 VA
	5 Second	4000 VA	4800 VA	4000 VA	4000 VA	5000 VA	4000 VA
	30 Minutes	2500 VA	3200 VA	2500 VA	3200 VA	4000 VA	4000 VA
AC Input Current Maximum		30 amps AC	30 amps AC	30 amps AC	30 amps AC	30 amps AC	30 amps AC
AC Input Voltage Range (MATE Adjustable)		80 to 150 VAC	80 to 150 VAC	80 to 150 VAC	80 to 150 VAC	80 to 150 VAC	80 to 150 VAC
AC Input Frequency Range		54.0 to 66.0 Hz	54.0 to 66.0 Hz	54.0 to 66.0 Hz	54.0 to 66.0 Hz	54.0 to 66.0 Hz	54.0 to 66.0 Hz
DC Input Range		10.5 to 17.0 VDC	21.0 to 34.0 VDC	28.0 to 45.3 VDC	10.5 to 17.0 VDC	21.0 to 34.0 VDC	28.0 to 45.3 VDC
Continuous Battery Charge Output		80 amps DC	55 amps DC	35 amps DC	125 amps DC	85 amps DC	45 amps DC
Minimum Recommended DC Breaker		OBDC-250	OBDC-175	OBDC-125	OBDC-250	OBDC-250	OBDC-175
Warranty		Standard 2 year / Optional 5 year			Standard 2 year / Optional 5 year		
Weight	Unit	62.6 lbs (28.4 kg)			61 lbs (27.7 kg)		
	Shipping	67 lbs (30 kg)			64 lbs (29 kg)		
Dimensions (H x W x L)	Unit	13 x 8.25 x 16.25" (33 x 21 x 41 cm)			12 x 8.25 x 16.25" (30 x 21 x 41 cm)		
	Shipping	21.75 x 13 x 22" (55 x 33 x 56 cm)			21.75 x 13 x 22" (55 x 33 x 56 cm)		

European Specifications

		Sealed Models			*Vented Models*		
		FX2012ET	**FX2024ET**	**FX2348ET**	**VFX2612E**	**VFX3024E**	**VFX3048E**
Nominal DC Input Voltage		12 VDC	24 VDC	48 VDC	12 VDC	24 VDC	48 VDC
Continuous Power Rating at 25° C		2000 VA	2000 VA	2300 VA	2600 VA	3000 VA	3000 VA
AC Voltage/Frequency		230 VAC 50 Hz	230 VAC 50 Hz	230 VAC 50 Hz	230 VAC 50 Hz	230 VAC 50 Hz	230 VAC 50 Hz
Continuous AC RMS Output at 25° C		8.7 amps AC	8.7 amps AC	10.0 amps AC	11.3 amps AC	13.0 amps AC	13.0 amps AC
Idle Power	Full	~ 20 Watts	~ 20 Watts	~ 23 Watts	~ 20 Watts	~ 20 Watts	~ 23 Watts
	Search	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts
Typical Efficiency		90%	92%	93%	90%	92%	93%
Total Harmonic Distortion	Typical	2%	2%	2%	2%	2%	2%
	Maximum	5%	5%	5%	5%	5%	5%
Output Voltage Regulation		± 2%	± 2%	± 2%	± 2%	± 2%	± 2%
Maximum Output Current	Peak	28 amps AC	35 amps AC	35 amps AC	28 amps AC	35 amps AC	35 amps AC
	RMS	20 amps AC	25 amps AC	25 amps AC	20 amps AC	25 amps AC	25 amps AC
AC Overload Capability	Surge	4600 VA	5750 VA	5750 VA	4600 VA	5750 VA	5750 VA
	5 Second	4000 VA	4800 VA	4800 VA	4000 VA	4800 VA	4800 VA
	30 Minutes	2500 VA	3100 VA	3100 VA	3100 VA	3300 VA	3300 VA
AC Input Current Maximum		30 amps AC	30 amps AC	30 amps AC	30 amps AC	30 amps AC	30 amps AC
AC Input Voltage Range (MATE Adjustable)		160 to 300 VAC	160 to 300 VAC	160 to 300 VAC	160 to 300 VAC	160 to 300 VAC	160 to 300 VAC
AC Input Frequency Range		44 to 56 Hz	44 to 56 Hz	44 to 56 Hz	44 to 56 Hz	44 to 56 Hz	44 to 56 Hz
DC Input Voltage Range		10.5 to 17.0 VDC	21.0 to 34.0 VDC	42.0 to 68.0 VDC	10.5 to 17.0 VDC	21.0 to 34.0 VDC	42.0 to 68.0 VDC
Continuous Battery Charge Output		100 amps DC	55 amps DC	35 amps DC	120 amps DC	85 amps DC	42 amps DC
Minimum Recommended DC Breaker		OBDC-250	OBDC-175	OBDC-100	OBDC-250	OBDC-250	OBDC175
Warranty		Standard 2 year / Optional 5 year			Standard 2 year / Optional 5 year		
Weight	Unit	62.6 lbs (28.4 kg)			61 lbs (27.7 kg)		
	Shipping	67 lbs (30 kg)			64 lbs (29 kg)		
Dimensions (H x W x L)	Unit	13 x 8.25 x 16.25" (33 x 21 x 41 cm)			12 x 8.25 x 16.25" (30 x 21 x 41 cm)		
	Shipping	21.75 x 13 x 22" (55 x 33 x 56 cm)			21.75 x 13 x 22" (55 x 33 x 56 cm)		

Charge Controller

MX60

The MX60 raises the bar for high performance solar controllers. OutBack's ingenuity and engineering experience has been combined to maximize the output power of your expensive solar array. Our real time active Maximum Power Point Tracking (MPPT) system ensures that your solar array is operating at its peak power point regardless of age, shading or environmental conditions. Systems with large solar arrays are now a snap thanks to the MX60's 60 amp DC output current rating for 12, 24 or 48 VDC systems - all with just one product model!

Real wiring flexibility of your solar array is finally here because of the MX60's wide range DC input, up to 150 VOC. The ability to step-down a high voltage solar array to a low voltage battery can save you money by reducing the size of wire required and making the installation simpler and faster. Our smart multistage recharging process ensures your batteries are recharged efficiently and gently to prolong battery life and achieves the highest possible performance.

All of the MX60's status information is displayed on the large built-in 3.1" (8 cm) backlit LCD screen. Monitoring your solar array's performance is easy because of the included data logging system that automatically records the last 64 days of system operation. OutBack's network communication system allows your MX60 to communicate with the rest of your OutBack system, eliminating multiple product interaction problems and allowing remote monitoring via the OutBack MATE display up to 1000 feet / 300 meters away.

MX60 Specifications

Nominal Battery Voltage		12, 24, 32, 36, 48, 54 or 60 VDC (Single model)
Output Current		60 amps maximum with adjustable current limit for smaller systems
Maximum Solar Array Size		12 VDC systems 800 Watts / 24 VDC systems 1600 Watts / 48 VDC systems 3200 Watts
PV Open Circuit Voltage (VOC)		150 VDC absolute maximum coldest conditions / 135 VDC start-up and operating maximum
Standby Power Consumption		1 Watt or less
Charging Regulation		Five Stages: Bulk, Absorption, Float, Silent and Equalization
Voltage Regulation Set points		10 to 80 VDC user adjustable with password protection
Equalization Voltage		Up to 5.0 VDC above Absorb Set point Adjustable Timer - Automatic Termination when completed
Battery Temperature Compensation		Automatic with optional RTS installed / 5.0 mV per °C per 2V battery cell / 30 mV per °C for 12 VDC system
Voltage Step-Down Capability		Can charge a lower voltage battery from a higher voltage PV array
Power Conversion Efficiency	Typical	98% at 60 amps with a 48 V battery and nominal 48 V solar array
Status Display		3.1" (8 cm) backlit LCD screen with 4 lines with 80 alphanumeric characters total
Remote Interface		Proprietary network system using RJ 45 Modular Connectors with CAT 5e Cable (8 wires)
Data Logging		Last 64 days of operation
		amp hours, watt hours and time in float for each day along with total lifetime power production
Hydro / Wind Turbine Applications		Consult factory for approved turbines
Positive Ground Applications		Requires two pole breakers for switching both positive and negative conductors on both solar array and battery connections
Operating Temperature Range		Minimum -40° to maximum 60° C (Power capacity of the controller is derated when above 25° C)
Environmental Rating		Indoor Type 1
Conduit Knockouts		Two .5" (13 mm) and .75" (19 mm) on the back; One .75" (19 mm) and 1" (25 mm) on each side; Two .75" (19 mm) and 1" (25 mm) on the bottom
Warranty		Standard 2 year / Optional 5 year
Weight	Unit	11.6 lbs (5.3 kg)
	Shipping	14 lbs (6.4 kg)
Dimensions (H x W x L)	Unit	13.5 x 5.75 x 4" (40 x 14 x 10 cm)
	Shipping	18 x 11 x 8" (46 x 30 x 20 cm)

Use appropriate wire size in accordance with NEC.
Note * Add 1% to the solar arrays open circuit voltage for every 2.5° C expected below the 25° C standard panel rating (STC). The resulting value must be below 150 VDC at the lowest expected temperatures conditions and less than 135 VDC for typical conditions to ensure reliable operation.

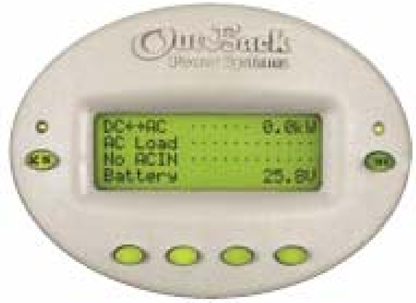
System Display and Controller

MATE

The MATE system display and controllers are complete management tools for your OutBack Power system. Through the use of a single MATE you can remotely manage and monitor multiple inverter/chargers, MX60s and any future OutBack power conversion and control products.

The MATE and MATE2 are packed full of features to make system management simple. The easy-to-read 3.1" (8 cm) LCD is backlit for dark operating conditions. Four soft keys allow easy context-based navigation of menus and functions. Two hot keys give immediate access to AC and inverter functions.

A built-in clock and calendar function enables timer based programming of inverter and charger operation. This permits you to set the system to work with time-of-day power rates or to limit a generator's run time to a specific time period of the day or week. All of your settings are stored in permanent memory to eliminate the need to reprogram in the event of a system shutdown or battery replacement. The MATE and MATE2 include a RS232 port with DB9 jack for connection to the serial port of a PC computer. Through the use of optional WinVerter software you can perform such operations as data logging and graphical display of the system's operation and performance.



MATE

MATE2 and MATE2M

MATE2M

The MATE2M is the same technology as the MATE and MATE2 but is designed to be used with your M-series inverter/chargers in mobile applications. Incorporating a more simplified menu, the settings needed for mobile power system management are more quickly accessed. A flush mount case design makes installation in boats and RVs more compact and attractive.

Communication with multiple products requires optional HUB

MATE Specifications

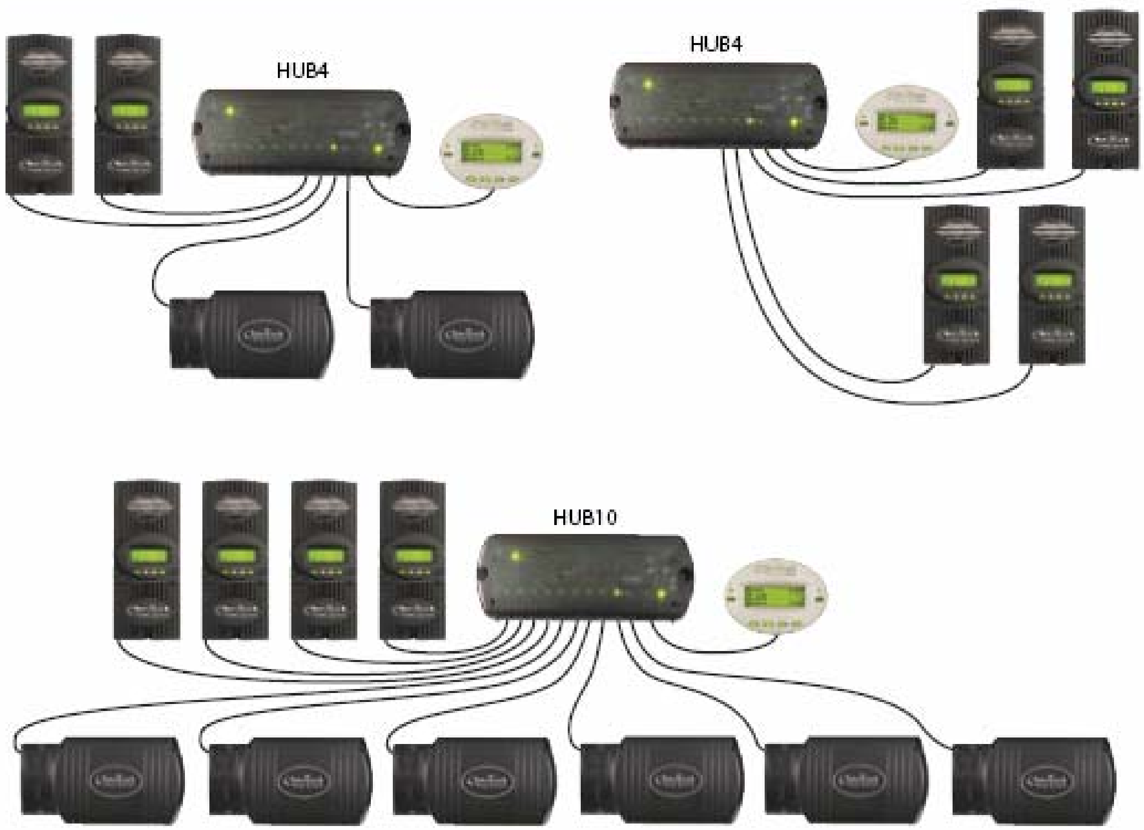
MATE		Surface mount with RS232	Grey
MATE2		Flush mount with RS232	Black
MATE2M		Flush mount without RS232	Black
Interface Display		3.1" (8 cm) backlit LCD	
Control Keypad		6 backlit silicone keys - dedicated inverter and AC input keys	
Status Indicators		Two LED Status Indicators	
Communication Protocol		Proprietary OutBack Multi-drop using an OutBack HUB4 or HUB10	
Interconnection Cabling		Standard CAT 5 network cable with RJ45 modular jack - 50' (5 m) included	
PC Computer Interface		RS232 opto-isolated DB9 jack 9600 baud serial communication	
Microprocessor		16 MHz low power consumption version	
Set point and Data Memory		32K non-volatile flash RAM	
Clock / Calendar		On-board real time clock with battery backup	
Environmental Rating		Indoor Type 1	
Maximum Cable Length		1000' (300 m)	
Warranty		Standard 2 year / Optional 5 year	
Weight	Shipping	1 lb (.5 kg)	
Dimensions (H x W x L)	Shipping	5.75 x 4.25 x 2" (15 x 11 x 5 cm)	

Communications Manager

HUB

The HUB system communications managers are the backbone of your networked OutBack power conversion system. The OutBack HUB communicates stacking, load share and power save off/on signals. Interconnection cabling is standard Ethernet CAT5 with RJ45 modular jacks. Through the use of a HUB, your system is completely coordinated and managed by the MATE.

HUB Specifications		HUB4	HUB10
Number of Ports		4 Plus MATE	10 Plus MATE
Weight	Unit	1 lb (.5 kg)	1 lb (.5 kg)
	Shipping	3 lbs (1.4 kg)	3 lbs (1.4 kg)
Dimensions (H x W x L)	Unit	10.5 x 6.25 x 1.27" (27 x 16 x 3 cm)	10.5 x 6.25 x 1.27" (27 x 16 x 3 cm)
	Shipping	12 x 6 x 5" (31 x 15 x 13 cm)	12 x 6 x 5" (31 x 15 x 13 cm)



Remote Temperature Sensor

RTS

The OutBack Remote Temperature Sensor (RTS) is a necessary tool for proper battery charging. All OutBack products with integrated battery charging have a temperature compensation system built-in which benefits from the installation of the optional RTS. The RTS ensures that your OutBack system knows the precise ambient temperature so that it can recharge your batteries safely and efficiently. Systems with multiple OutBack products connected to one HUB4 or HUB10 require only a single RTS to be installed.

15' (5 m) cable

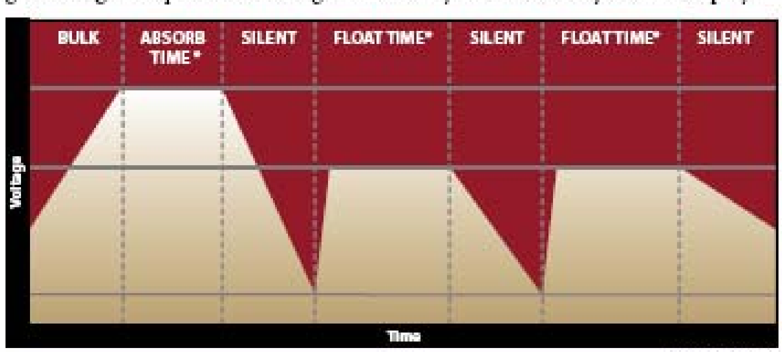
Battery Charging

Batteries are a key component in backup and off-grid systems, often serving as the only energy storage device. To guarantee that they function properly it is important that your batteries are maintained. A chief part of this maintenance is proper charging. Your batteries should always be maintained above a 50% level of charge and receive a complete recharge once a month to ensure operation at peak performance. Prolonged use of the battery below a 50% state of charge will adversely affect the long-term health of the battery and can result in premature failure.

The multistage charging process uses several regulation stages to allow fast recharging of the battery energy storage system while ensuring a long battery life, high performance and efficient operation of the overall system. The charging process begins with the BULK stage, where maximum current is sent to the batteries until the target "absorb" voltage is reached and the absorb stage of the charge begins. During ABSORB, the charger provides the batteries with the just enough current to hold at the set voltage for a preset amount of time. Following this cycle, the charging system changes between available OutBack charging products. Using the MX-60, the batteries enter the FLOAT stage where they are given a maintenance charge until there is no excess renewable energy. The FX or VFX inverter/charger will go into SILENT mode where the charger turns off until the battery voltage drops to the "re-float" setting. At this point the inverter/charger initiates the maintenance FLOAT charge. This method reduces fuel and utility consumption.

It should be noted that the temperature of your batteries has an impact on the charging process. The OutBack RTS should be used to monitor this. In higher ambient temperatures, the battery charging regulation settings will be reduced to prevent overcharging of the batteries. Conversely, in lower ambient temperature conditions, the regulation settings will be increased to ensure complete recharging of the batteries.

Batteries are composed of a group of individual cells. Through normal use, the charge of each individual cell will not be equal to the other cells. To address this, your batteries should be EQUALIZED either once each month or once every few months depending on usage. During the equalization charge the electrolyte in the battery is stirred up by gas bubbles, which help to create an equal mixture of water and acid. Simultaneously the full cells are overcharged which allows the low cells to "catch up" and all of the active material in the battery to be reconverted to its charged state. Depending on usage, the hardened battery plate material that is no longer active in the battery-sulfation can also be reduced by an equalization charge.



** MATE Adjustable*

Auto Transformer

PSX-240

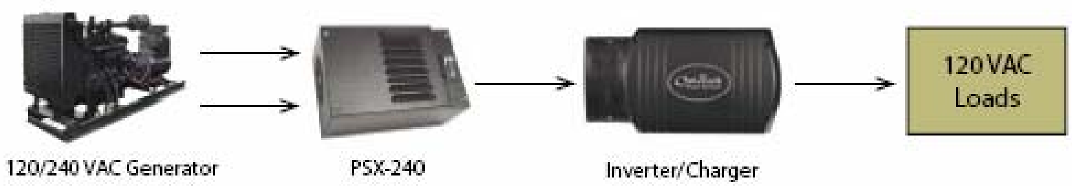
The OutBack PSX-240 auto transformer can be used for step-up, step-down, generator and split phase output balancing or as a series stacked inverter to load balancing auto-former. Incorporating a transformer with 120 volt/30 amp primary and secondary side, a temperature activated cooling fan and a 25 amp dual breaker in a steel enclosure, the PSX-240 is ready to install in your custom application. Use for 120 or 240 VAC 60 Hz systems only.

Powering 240 volt items like deep well pumps with a single 120 volt inverter is possible thanks to the PSX-240's step-up capability. Its step-down feature allows you to charge your batteries with a 240 volt generator through a single 120 volt inverter. The PSX-240's ability to balance the output of series stacked inverter/chargers makes it a critical item when using the OutBack stacking 120/240 VAC configuration.

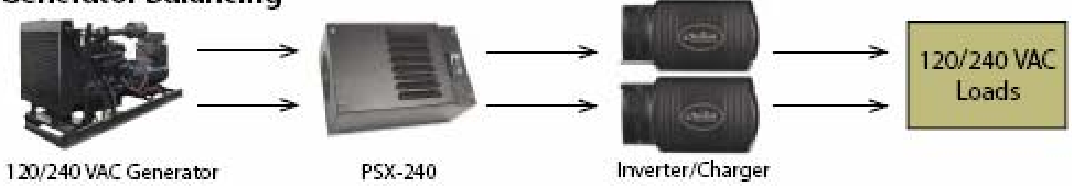
The X-240 is also available without the enclosure, for installation inside the PS2AC or PS4AC enclosures.

Step-Up

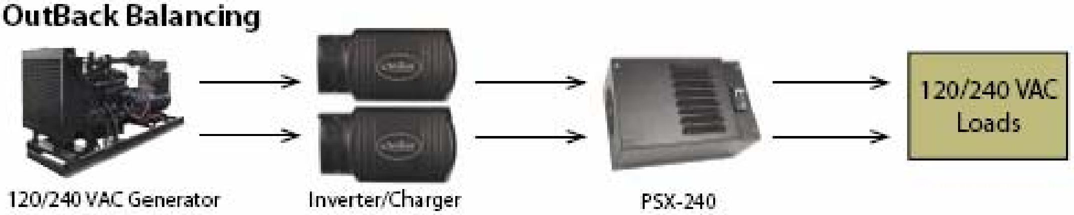
Step-Down



Generator Balancing



OutBack Balancing



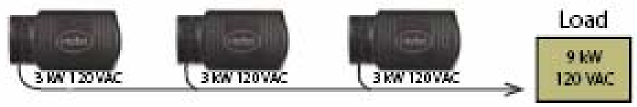
Stacking

At OutBack, we adhere to a philosophy that a power system should be fully customizable to address your specific needs. Therefore we set out to create the world's only group of inverter/chargers that use a truly modular architecture. This modular architecture uses the next generation of a technique referred to as "stacking" to enable you to tailor your system for higher output power, increased charging capabilities and/or three-phase power configuration.

Whether stacked in parallel, classic series, series/parallel or three-phase there is always an inverter/charger which performs the task of Master. The Master talks to the other units through the HUB system communications manager while performing three major roles, keeping all inverter/chargers properly phased, controlling inverter and charger output levels, as well as putting unused inverters into Power Save mode to improve efficiency at low AC load levels.

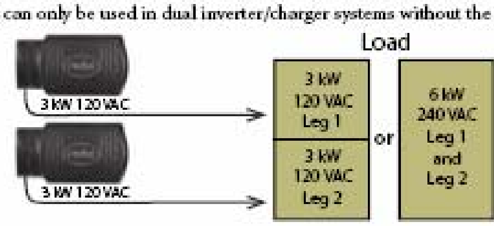
Parallel Stacking - More power at same output voltage

When the inverter/chargers are stacked in parallel all inverter and charger outputs are combined. This means that each inverters AC output is added up to equal your total system AC output, up to 36,000 watts, in phase at the same 120 VAC/60 Hz or 230 VAC/50 Hz output voltage. Charging output amperage is also combined in this same manner.



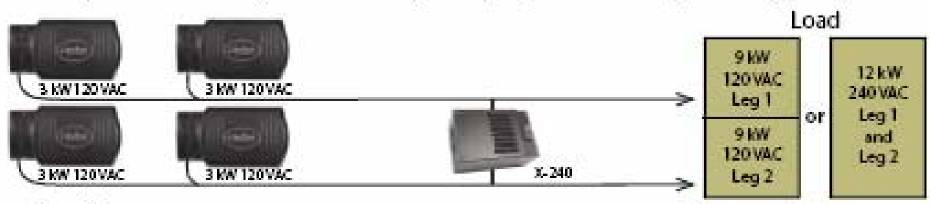
Classic Series Stacking - More power at higher output voltage

Stacking inverter/chargers in classic series provides a system with split phase 120/240 VAC. This method does not allow balancing between separate legs on a system and is can only be used in dual inverter/charger systems without the X-240 Auto Transformer.



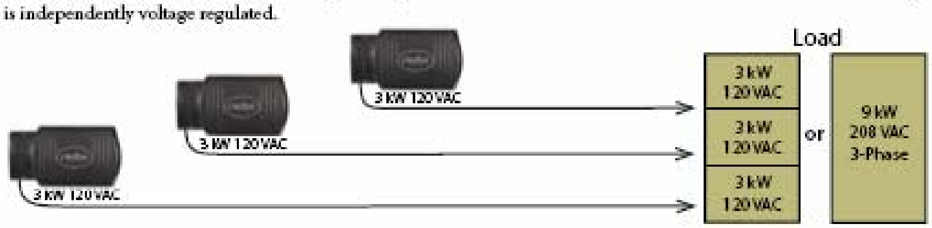
OutBack Series/Parallel Stacking - More power at all output voltages

Series/Parallel stacking or OutBack (OB) stacking is unique to OutBack inverter/chargers. Never before has it been possible to have inverter/chargers balancing loads intelligently between two legs of AC power while seamlessly changing between series and parallel. OB Stacking uses the X-240 auto transformer to balance the loads between the two separate series legs of a system. The X-240 allows AC loads on leg 1 and leg 2 to be powered by any combination of inverter/chargers within your system. Even if there are only two inverter/chargers, connected in series, they can also function as if connected in parallel. This allows larger AC loads to be operated by a system without risking overloading one of the 120 VAC outputs.



3-Phase Stacking - More power for three-phase loads

Three inverter/chargers can be configured to provide 120/208 VAC or 230/400VAC four wire "Wye/Star" three-phase AC Power. An inverter/charger is used to power each of the three legs for 3-phase AC power. The loads on each of the inverters does not need to be kept balanced, each phase is independently voltage regulated.



Grid-Interactive System

PS1

The PS1 is advanced engineering and refinement that you have come to expect from OutBack Power in a next generation grid-interactive solar electric system. The system's battery backup is a silent and hands-off alternative to noisy and maintenance intensive generators.

In side-by-side "real world" testing the PS1 system performs within 5% of the industry leading battery-less grid-tie inverter, translating into more savings when using net metering. The same field proven MPPT technology found in the MX60 solar charge controller is featured in the PS1. This cutting edge concept gives the system the ability to use your PV array at its peak output. Uninterrupted AC power is provided by the PS1's system's true sinewave inverter that has an industry leading, California Energy Commission (CEC) certified, efficiency of 91%, thus guaranteeing that your household appliances run seamlessly while utilizing all available solar power. Your recommended AGM batteries are maintained and charged by an innovative OutBack multistage charging process, a valuable feature that assists in providing reliable backup power and a battery life up to 10 years. An ultra-fast 16 millisecond transfer switch guarantees that even sensitive backup loads, such as computers, never know when a grid outage occurs.

Like every OutBack Power product, the PS1 is rugged. All components are protected within an aluminum type 3R rainproof enclosure. The ETL listed system is pre-wired by OutBack engineers to ensure that the PS1 system works reliably for years to come. A standard 5 year warranty provides peace of mind and satisfies state rebate requirements.

PS1 Specifications

Model	Description
PS1 - 3000	Vented Inverter/Charger with MX60 and HUB4
PS1 - 2500	Sealed Inverter/Charger with MX60 and HUB4
PS1 - BE	Battery Enclosure with all cables *(Order batteries separately)*

PS1 Options

Model	Rating	Version	Width
OBAC-20	25 amp 120 VAC	Single Pole OutBack	.05" (13 mm)
OBAC-15	15 amp 120 VAC	Single Pole OutBack	.05" (13 mm)

Model	Rating	Version	Width
OBPV-8	8 amps 125 VDC	Single Pole OutBack	.05" (13 mm)
OBPV-10	10 amps 125 VDC	Single Pole OutBack	.05" (13 mm)
OBPV-15	15 amps 125 VDC	Single Pole OutBack	.05" (13 mm)

PS1 Specifications

		Sealed Models PS1-2500	Vented Models PS1-3000
Continuous Power Rating	At 40° C	2500 VA	3000 VA
	At 25° C	3000 VA	3600 VA
AC Voltage / Frequency Output		120 VAC 60 Hz	120 VAC 60 Hz
AC Input Current Maximum	AC Transfer Switch	50 amps AC	50 amps AC
	Battery Charger	16 amps AC with automatic back-off	20 amps AC with automatic back-off
Maximum AC Surge Current	Peak (1 millisecond)	70 amps AC	70 amps AC
	RMS (5 seconds)	50 amps AC	50 amps AC
Maximum PV Array Wattage		3300 watts DC stc rating	3300 watts DC stc rating
PV Open Circuit Voltage	Maximum	150 VDC	150 VDC
MPPT Input Voltage Range		44 to 135 VDC	44 to 135 VDC
PV Array Ground Fault Protection		Standard - 80 amp DC	Standard - 80 amp DC
Inverter Efficiency	Typical	91% (not CEC Certified)	91% (CEC Certified)
	Peak	93%	93%
MPPT Efficiency		98%	98%
Overall System Efficiency	Typical	89%	89%
	Peak	92%	92%
Battery Voltage - Nominal		48 VDC	48 VDC
Minimum / maximum operating range		40 to 60 VDC	40 to 60 VDC
Battery Charge Rate	Inverter	35 amps DC	45 amps DC
	MX60	60 amps DC	60 amps DC
AC Output Voltage Regulation	Typical	5%	5%
	Nominal	120 VAC	120 VAC
AC Output Current	Inverting	25.0 amps AC	30.0 amps AC
	Selling	20.8 amps AC	25.0 amps AC
Total Harmonic Distortion	Inverting	2% VAC THD	2% VAC THD
	Selling	< 5% current THD per UL1741 conditions	< 5% current THD per UL1741 conditions
AC Transfer Switch Speed	Typical	< 16 Milliseconds	< 16 Milliseconds
Battery Temperature Sensor		Included	Included
Operating Temperature Range		-40° C to 60° C (power derated above 25° C)	-40° C to 60° C (power derated above 25° C)
Recommended Minimum Energy Storage		4 kWHRS at 80% discharge	4 kWHRS at 80% discharge
Recommended Batteries		Four AGM type 31 or type 27 sealed VRLA	Four AGM type 31 or type 27 sealed VRLA
Communications		Optional MATE system display with RS232 port	Optional MATE system display with RS232 port
Enclosure Materials		Powder coated aluminum, stainless steel hardware	Powder coated aluminum, stainless steel hardware
Mounting		Wall mount, 16 on center studs	Wall mount, 16" on center studs
Recommended Mounting Hardware		5/16 x 2.5" Lag Bolts - three per side minimum	5/16 x 2.5" Lag Bolts - three per side minimum
System Enclosure Dimensions (H x W x D)	Unit	31.3 x 17.25 x 12.9" (80 x 44 x 33 cm)	31.3 x 17.25 x 12.9" (80 x 44 x 33 cm)
	Shipping	40.5 x 20.5 x 17.25" (103 x 52 x 44 cm)	40.5 x 20.5 x 17.25" (103 x 52 x 44 cm)
Battery Enclosure Dimensions (H x W x D)	Unit	36.25 x 17.25 x 12.55" (92 x 44 x 32 cm)	36.25 x 17.25 x 12.55" (92 x 44 x 32 cm)
	Shipping	43.25 x 20.25 x 16.75" (110 x 51 x 43 cm)	43.25 x 20.25 x 16.75" (110 x 51 x 43 cm)
System Weight	Unit	107 lbs (49 kg)	107 lbs (49 kg)
	Shipping	117 lbs (53 kg)	117 lbs (53 kg)
Battery Enclosure Weight (without batteries)	Unit	29 lbs (13 kg)	29 lbs (13 kg)
	Shipping	47 lbs (21 kg)	47 lbs (21 kg)
Certifications		ETL certified to the UL1741 standard	ETL certified to the UL1741 standard
Anti-Islanding Measures		UL1741 compliant	UL1741 compliant
Warranty		5 year limited repair warranty standard	5 year limited repair warranty standard
Field Installed Options		MATE or MATE2 remote system display	MATE or MATE2 remote system display
		OBAC breakers for additional AC load circuits	OBAC breakers for additional AC load circuits
		OBPV breakers for PV array series string protection	OBPV breakers for PV array series string protection

System Accessories

PS2

OutBack Power offers compact enclosures for all of the AC and DC components of a renewable energy power conversion system. The PS2 series saves time, money and space by combining the disconnects, over-current protection devices and control components into easy-to-install enclosures. Capable of supporting one or two OutBack FX series inverter/chargers, up to three MX60 charge controllers, a MATE system controller and all the associated AC and DC components.

The OutBack PS2 series can be fully customized to your application and ordered pre-wired or as individual components for field assembly.

PS2AC Breaker Panel

The PS2AC is engineered to be a code-compliant steel enclosure for AC power routing and management.

- ETL listed indoor type powder coated enclosure
- Ground terminal bus bar bonded to cabinet
- One white insulated AC neutral terminal bus bar
- Two black insulated bus bars for Hot AC IN and OUT Leg 1
- Two red insulated bus bars for Hot AC IN and OUT Leg 2
- Knockouts for eight additional OutBack AC load breakers
- Provisions for mounting an X-240 and cooling fan
- Knockouts on five surfaces to facilitate conduit and inverter connections

Shown with 120/240 VAC/60 Hz dual inverter bypass (50D) or 230 VAC/50 Hz dual inverter bypass (50DE) and additional AC load breakers

PS2DC Breaker Panel

The PS2DC is a code-compliant steel enclosure engineered to contain all DC power routing and management components.

- ETL listed indoor type powder coated enclosure with plenty of conduit knockouts
- Knockouts for one additional inverter battery breaker and eight 3/4" (19 mm) breakers
- 500 amp 50 mVolts DC current shunt standard
- Battery negative/ground bus bar standard
- Battery positive bus bar for DC loads and PV arrays included standard
- Knockouts for battery conduit, MX60 interconnect and stacking another PS2DC
- Use for negative or positive ground systems
- Knockouts on five surfaces to facilitate conduit - inverter connections and additional MX60s

Shown with DC breakers and DC-GFP/2 - order separately

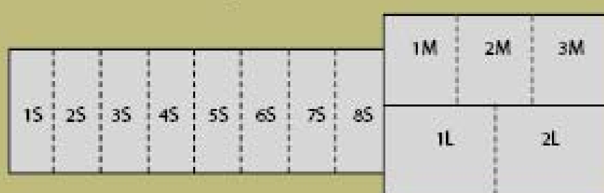
PS2AC and PS2DC Breaker Panel Specifications

Model	Standard Breakers	Dimensions Unit (H x W x D)	Dimensions Shipping (H x W x D)	Weight Unit
PS2AC-50D	50 amp 120/240 VAC 60 Hz Bypass assembly	18.25 x 11.5 x 9" (46 x 29 x 23 cm)	21 x 15 x 13" (53 x 38 x 33 cm)	26 lbs (12 kg)
PS2AC-50DE	50 amp 120/230 VAC 50 Hz Bypass assembly	18.25 x 11.5 x 9" (46 x 29 x 23 cm)	21 x 15 x 13" (53 x 38 x 33 cm)	24 lbs (11 kg)
PS2AC	No breakers included	18.25 x 11.5 x 9" (46 x 29 x 23 cm)	21 x 15 x 13" (53 x 38 x 33 cm)	23 lbs (10 kg)
PS2DC-175	175 amp DC Breaker	18.25 x 11.5 x 9" (46 x 29 x 23 cm)	21 x 15 x 13" (53 x 38 x 33 cm)	24 lbs (11 kg)
PS2DC-250	250 amp DC Breaker	18.25 x 11.5 x 9" (46 x 29 x 23 cm)	21 x 15 x 13" (53 x 38 x 33 cm)	24 lbs (11 kg)
PS2DC	No Breakers included	18.25 x 11.5 x 9" (46 x 29 x 23 cm)	21 x 15 x 13" (53 x 38 x 33 cm)	23 lbs (10 kg)

OutBack PS2AC Bypass Assemblies Specifications - for field installations in bare PS2AC version

Model	Inverter Output	Bypass Breaker Rating	Input Breaker Rating	Output Breaker Rating
PS2-IOB-50D	120/240 VAC 60 Hz	50 amps at 120/240 VAC	50 amps at 120/240 VAC	50 amps at 120/240 VAC
PS2-IOB-50DE	230 VAC 50 Hz	50 amps at 230 VAC	50 amps at 230 VAC	50 amps at 230 VAC

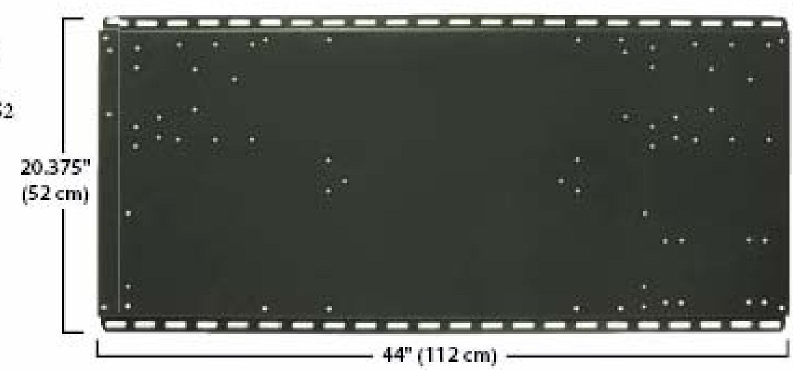
PS2 DC Breaker Configurations



The PS2DC Breaker Panel has eight small .75" (19 mm), three medium 1" (26 mm) or two large 1.5" (32 mm) breaker positions. The small sizes are 1-80 amps, medium sizes are 100 or 125 amps an the large sizes are 175 or 250 amps.

PS2 Mounting Plate

The PS2MP is a one piece, powder coated steel mounting plate. It is designed to accomodate all your PS2 series accessories as well as up to two OutBack Inverter/Chargers.



PS2 Mounting Plate Specifications

Model	Dimensions Unit (H x W x D)	Dimensions Shipping (H x W x D)	Weight Shipping
PS2MP	20.375 x 44 x .875" (52 x 112 x 2 cm)	23 x 48 x 2.5" (58 x 122 x 6 cm)	24 lbs (11 kg)

System Accessories

PS4

The PS4 series is the ideal AC and DC enclosure system for medium to large size renewable energy power conversion system. The PS4 is comprised of two compact enclosures for all of your system's AC and DC components. It saves time, money and space by combining disconnects, over-current protection devices and control components into easy-to-install enclosures.

The PS4 is capable of supporting up to four OutBack FX series inverter/chargers, six MX60 charge controllers, a MATE system controller and all the required AC and DC components and wiring.

The OutBack PS4 system can be fully customized to your application and ordered pre-wired or as individual components for field assembly.

PS4AC Breaker Panel

The PS4AC is a NEC compliant enclosure engineered to contain all the AC overcurrent protection and power management components.

- ETL listed indoor type powder coated steel enclosure with plenty of knockout and mounting provisions for a variety of OutBack products.
- Available without the AC bypass assembly included (PS4AC) *(Order all required AC breakers separately)*
- Available with a four FX inverter ready 60 amp 120/240VAC AC bypass assembly (PS4-IOB-60Q) for systems with AC generators or utility grid connections up to 15 kW
- Available with a four FX inverter ready 100 amp 120/240VAC AC bypass assembly (PS4-IOB-100Q) for systems with large AC generators or grid connections over 15kW
- Available with a four FX inverter ready 60 amp 230VAC 50 Hz AC bypass assembly (PS4-IOB-60QE) for export applications
- Ground terminal bus bar bonded to cabinet
- One white insulated AC neutral terminal bus bar
- Two black insulated AC hot/leg 1 terminal bus bars
- Two red insulated AC hot/leg 2 terminal bus bars
- Complete wiring kit is included when the AC bypass kit is included or ordered separately
- Space provided for up to 13 additional OutBack AC load breakers
- Provisions for mounting an X-240 autotransformer and optional cooling fan
- Knockouts on five surfaces to facilitate conduit and inverter connections

PS4DC Breaker Panel

The PS4DC is a NEC compliant enclosure engineered to contain all the DC overcurrent protection and power management components.

- ETL listed indoor type powder coated steel enclosure with plenty of knockout and mounting provisions for a variety of OutBack products.
- Available without any DC breakers included (PS4DC) *(Order all required DC breakers separately)*
- Also available with one inverter/battery DC breaker included standard (PS4DC-175 amp or PS4DC-250)
- Space provided for up to four large breakers (175 or 250 amp) or six medium breaker (100 or 125 amps) - can also be combined as two large and three medium breakers
- Space provided for an additional ten small breakers (1 to 80 amps 150 VDC rated) as well as the OutBack PV-GFP/2 ground fault protection system
- 500 amp 50 mVolts DC current shunt standard
- One combined negative/ground bus bar attached to the DC shunt included standard
- One positive terminal bus bar (TBB-R) for DC loads or PV array combining included standard
- Can be used for negative or positive ground systems
- Knockouts on five surfaces to facilitate conduit and inverter connections

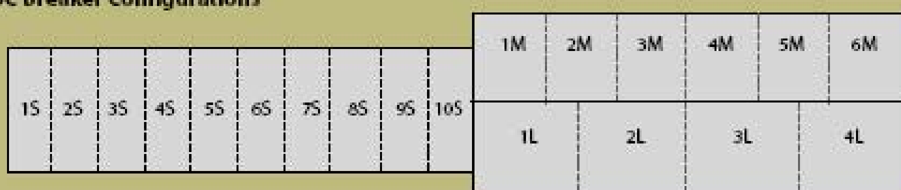
PS4 Breaker Panel Specifications

Model	Standard Breakers	Dimensions Unit (H x W x D)	Dimensions Shipping (H x W x D)	Weight Shipping
PS4AC-60Q	60 amp 120/240VAC 60 Hz Bypass assembly	32.5 x 10.25 x 8.875" (83 x 26 x 23 cm)	36 x 14 x 13" (91 x 36 x 33 cm)	35 lbs (16 kg)
PS4AC-100Q	100 amp 120/240VAC 60 Hz Bypass assembly	32.5 x 10.25 x 8.875" (83 x 26 x 23 cm)	36 x 14 x 13" (91 x 36 x 33 cm)	35 lbs (16 kg)
PS4AC-60QE	60 amp 230VAC 50 Hz Bypass assembly	32.5 x 10.25 x 8.875" (83 x 26 x 23 cm)	36 x 14 x 13" (91 x 36 x 33 cm)	35 lbs (16 kg)
PS4AC	No bypass included	32.5 x 10.25 x 8.875" (83 x 26 x 23 cm)	36 x 14 x 13" (91 x 36 x 33 cm)	32 lbs (15 kg)
PS4DC-175	One 175 amp DC breaker	32.5 x 15.75 x 8.875" (83 x 40 x 23 cm)	36 x 19 x 13" (91 x 48 x 33 cm)	41 lbs (19 kg)
PS4DC-250	One 250 amp DC breaker	32.5 x 15.75 x 8.875" (83 x 40 x 23 cm)	36 x 19 x 13" (91 x 48 x 33 cm)	41 lbs (19 kg)
PS4DC	No breakers included	32.5 x 15.75 x 8.875" (83 x 40 x 23 cm)	36 x 19 x 13" (91 x 48 x 33 cm)	38 lbs (17 kg)

OutBack PS4AC Bypass Assemblies Specifications - for field installations in bare PS4AC version

Model	Inverter Output	Bypass Breaker	Input Breaker	Output Breaker
PS4-IOB-60Q	120/240 VAC 60 Hz	60 amps at 120/240 VAC	Four 50 amps at 120 VAC	Four 50 amps at 120 VAC
PS4-IOB-100Q	120/240 VAC 60 Hz	100 amps at 120/240 VAC	Four 50 amps at 120 VAC	Four 50 amps at 120 VAC
PS4-IOB-60QE	230 VAC 50 Hz	60 amps at 230 VAC	Four 30 amps at 230 VAC	Four 30 amps at 120/230 VAC

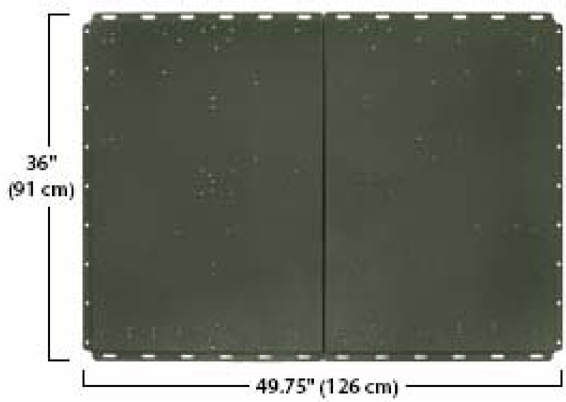
PS4DC Breaker Configurations



The PS4DC Breaker Panel has ten small .75" (19 mm), up to six medium 1" (26 mm) or four large 1.5" (32 mm) breaker positions. The small sizes are 1-80 amps, medium sizes are 100 or 125 amps an the large sizes are 175 or 250.

PS4 Mounting Plate

The PS4MP is a two part, powder coated steel mounting plate. It is designed to accomodate all your PS4 series accessories as well as up to four OutBack Inverter/Chargers.



PS4 Mounting Plate Specifications

Model	Dimensions Unit (H x W x D)	Dimensions Shipping (H x W x D)	Weight Shipping
PS4MP	36 x 49.75 x 1.125" (91 x 126 x 3 cm)	38.5 x 38.5 x 3" (117 x 98 x 8 cm)	46 lbs (21 kg)

System Components

OutBack AC Breakers

Hydraulic-Magnetic type breakers that are DIN rail "snap-in" mountable and can be used for input, output or load circuits. 1/2" (13 mm) wide.

OutBack AC Breaker Specifications

Model	Rating	Version	Width
OBAC-50	120VAC	Single Pole	0.5"(13 mm)
OBAC-50D	120/240VAC	Dual Pole	1.0"(26 mm)
OBAC-50-3P	120/208VAC	Three Pole	1.5"(39 mm)
OBAC-50DE	240VAC	Dual Pole	1.0"(26 mm)
OBAC-30	120VAC	Single Pole	0.5"(13 mm)
OBAC-30D	120/240VAC	Dual Pole	1.0"(26 mm)
OBAC-25D	120/240VAC	Dual Pole	1.0"(26 mm)
OBAC-20	120VAC	Single Pole	0.5"(13 mm)
OBAC-20D	120/240VAC	Dual Pole	1.0"(26 mm)
OBAC-15	120VAC	Single Pole	0.5"(13 mm)
OBAC-15D	120/240VAC	Dual Pole	1.0"(26 mm)

OutBack DC Breakers

Panel mounted Hydralic-Magnetic type breakers which can be used for DC sources, inverters or load circuits. 3/4" (18 mm) wide.

OutBack DC Breaker Specifications

Model	Current Rating	Stud Terminal Size	Width
OBDC-250	250 amp 125 VDC	3/8" stud	1.5" (39 mm)
OBDC-175	175 amp 125 VDC	3/8" stud	1.5" (39 mm)
OBDC-125	125 amp 125 VDC	5/16" stud	1.0"(26 mm)
OBDC-100	100 amp 125 VDC	5/16" stud	1.0"(26 mm)
OBDC-80	80 amp 150 VDC	5/16" stud	0.75" (19 mm)
OBDC-70	70 amp 150 VDC	1/4" stud	0.75" (19 mm)
OBDC-60	60 amp 150 VDC	1/4" stud	0.75" (19 mm)
OBDC-50	50 amp 150 VDC	1/4" stud	0.75" (19 mm)
OBDC-40	40 amp 150 VDC	1/4" stud	0.75" (19 mm)
OBDC-30	30 amp 150 VDC	1/4" stud	0.75" (19 mm)
OBDC-20	20 amp 150 VDC	1/4" stud	0.75" (19 mm)
OBDC-15	15 amp 150 VDC	1/4" stud	0.75" (19 mm)
OBDC-10	10 amp 150 VDC	1/4" stud	0.75" (19 mm)
OBDC-5	5 amp 150 VDC	1/4" stud	0.75" (19 mm)
OBDC-1	1 amp 150 VDC	1/4" stud	0.75" (19 mm)

OutBack PV Ground Fault Protection System

The OBDC-GFP/2 is required by the NEC for PV arrays mounted on residential dwelling roofs. It can be used with the PS2DC, PS4DC or PS1. An OBDC-GFP/2 protects wiring and system components for one or two PV arrays: dual 80 amp PV circuits 150 VDC max VOC. The OBDC-GFP/2 system includes the GFP unit, a ground bus bar, neutral and ground connection wiring and mounting hardware.

OutBack PV Ground Fault Protection Specifications

Model	Description	Stud Terminal Size
OBDC-GFP/2	80 amp at 150 VDC	2 Poles - Requires 3

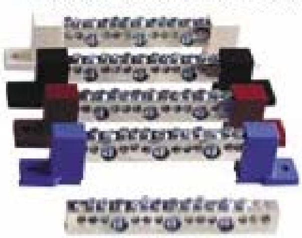
X-240 Auto Transformer

The same auto transformer and breakers as the PSX-240 but designed to be housed within the PS2AC or PS4AC. It can be used for step-up, step-down, generator and split phase output balancing or as a series stacked inverter-to-load balancing auto-former. It can also transfer up to 2kW (3kW with the optional X fan kit) from one side of the total power rating of the generator or the total power rating of an OutBack stacked series/parallel 120/240 VAC inverter/charger configuration.

X-Fan Kit

The X-Fan Kit increases the power rating of the X-240 to a maximum of 6 kVA continuous. Thermostatic controlled 120 VAC powered.

Terminal and Ground Bus Bars



Use for adding more wire terminations or for isolating multiple positive / negative circuits. All TBB and GBB models have three #1/0 to 14 AWG and eight #6 to 14 AWG screw type compression terminals, which means no ring lugs required. Available with black, white and red insulators. The Battery Bus is .25" (7 mm) thick tin plated copper and can be mounted on the back plate of the PS2DC / PS4DC or directly on the battery breaker terminals.

Conduit Adapters

Allows connection of the FX and VFX inverter/chargers to the PS2 and PS4 breaker panels or 2" conduit.

Mounting Brackets

The mounting bracket allows MX60 charge controllers to be mounted on the side of the PS2DC or PS4DC enclosures.

X-240 Auto Transformer Specifications

Model	Description
X-240	120/240 VAC 60 Hz
	2.0 kW without Fan Kit
	3.0 kW with X-Fan Kit
X-Fan Kit	Thermostatic controlled brushless fan 120 VAC Powered

Terminal and Ground Bus Bars Specifications

Model	Description
GBB	Ground Bus Bar not insulated
TBB	Terminal Bus Bar with black insulators
TBB-B	Terminal Bus Bar with blue insulators
TBB-R	Terminal Bus Bar with red insulators
TBB-W	Terminal Bus Bar with white insulators

Conduit Adapters Specifications

Model	Description
ACA	FX and VFX AC end
DCA	FX and VFX DC end

Mounting Brackets Specifications

Model	Description
PS2-CCB	One MX60
PS2-CCB2	Two MX60s
PS4-CCB2	Two MX60s

System Components

PV Array Combiner Box

The PSPV is a solar array combiner which can be used with a wide variety of system configurations and solar module types. The PSPV is designed to provide NEC code compliant series over current protection of the wiring of multiple PV modules or subarrays for connection to charge controllers, inverters or other systems components. The rainproof aluminum enclosure is easily field configured to match your PV system design and amperage requirements.

- Rainproof, outdoor Type 3R powder coated aluminum enclosure
- Approved for installation on both vertical and angled surfaces with a slope as little as 3-in-12 pitch - also can be pole mounted *(Brackets not included)*
- Designed for use with up to twelve OutBack's OBPV breakers for PV array configurations of 12 to 72 VDC systems - maximum open circuit voltage of 150 VDC
- Also can use the OutBack OBFH "touch safe" type fuse holders for high voltage systems - maximum open circuit voltage of 600 VDC
- Includes dual combining bus bars which can be installed to provide one or two separate PV output circuits from a single PSPV enclosure
- Includes one terminal bus bar (TBB) and has mounting holes for an additional TBB
- Includes two #1/0 AWG set-screw compression type box lug terminals for output wiring
- Includes one #1/0 AWG ground lug which can be mounted either on the inside or outside surface of the enclosure
- Two 1 inch side knockouts which can be punched out to allow for larger 1.25" (3 cm) conduit
- Eight .5" (13 mm) knockouts on bottom for PV module or subarray input wiring
- Clearance is provided on bottom and back main knockouts to allow up to a 2" (5 cm) conduit punch for larger cabling
- For negative or positive ground PV systems
- Enclosure ships without breakers or fuse holders *(Order separately)*

Photo courtesy of Bob-O Schultz, Electron Connection

Photovoltaic (PV) Array Breakers

PV breakers are Hydraulic-Magnetic type and are not affected by high ambient temperatures. All breakers have a 10 year warranty. Maximum of twelve OBPV in one PSPV enclosure.

PV Array Fuses and Fuse Holders

DIN rail snap-in mount with #8 AWG setscrew type compression terminals. Touch-safe design. Not rated for load make or load break usage. UL listed for up to 600 VDC. Maximum of eight fuse holders in one PSPV enclosure.

Terminal and Ground Bus Bars

Use for adding more wire terminations or for isolating multiple positive / negative circuits. Has three #1/0 to 14 AWG and eight #6 to 14 AWG screw type compression terminals, which means no ring lugs required.

PV Array Breakers Specifications

Model	Rating
OBPV-2	2 amps 150 VDC
OBPV-4	4 amps 150 VDC
OBPV-6	6 amps 150 VDC
OBPV-8	8 amps 150 VDC
OBPV-9	9 amps 150 VDC
OBPV-10	10 amps 150 VDC
OBPV-15	15 amps 150 VDC
OBPV-30	30 amps 150 VDC

PV Array Fuses Specifications

Model	Description
OBFH	Fuse Holder only
OBF-6	6 amp 600 VDC
OBF-10	10 amp 600 VDC
OBF-15	15 amp 600 VDC

Terminal and Ground Bus Bars Specifications

Model	Description
TBB	Terminal Bus bar with black insulators
GBB	Ground terminal Bus bar

Out B
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www.outbackpower.com

GoPower.com
8511 NW 61st Street . Miami FL . 33166 Phone: 305-592-6800 Fax: 305-592-5900 info@GoPower.com

16 kW Mitsubishi Fully Packaged Diesel Generator Set

SKU **553003**

- New
- 2 Year / 1,500 Hours Factory Warranty (Whichever comes first)
- Battery Charging Alternator
- Digital Control Panel
- Factory Loadbank Tested
- Mainline Circuit Breaker
- Skid Mounted
- Spring Mounted Vibration Isolators
- Dimensions (L x W x H - height does not include muffler): 55" x 28" x 41"
- 16 KW
- Weight (Pounds): 996
- 8 Hour Base Mounted Fuel Tank
- Diesel
- Industrial Muffler
- Single and 3 Phase Available
- Reconnectable
- Battery Rack and Cables (Batteries Not Included)
- Includes

3 Phase Available, please add $399

Options:
- 12 V Mitsubishi Battery Charger for Nexys Add $299.00
- Mitsubishi Genservice 500 (Filter Kit for 500 Hours) Add $82.99
- Optional 2 Year or 1000 Hour Extended Warranty: Add $255.00

Specifications may vary. Confirm full specs prior to ordering.

FOB Miami
In Stock

Available for Immediate Delivery
$7,399.00
ADD TO QUOTE

800-424-0007 or 305-592-6800

Low Lease Rates Available

Extend the warranty to 5 years for $999

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Base Tanks - Custom
Base Tanks - Stocked
Batteries
Battery Chargers
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Enclosures
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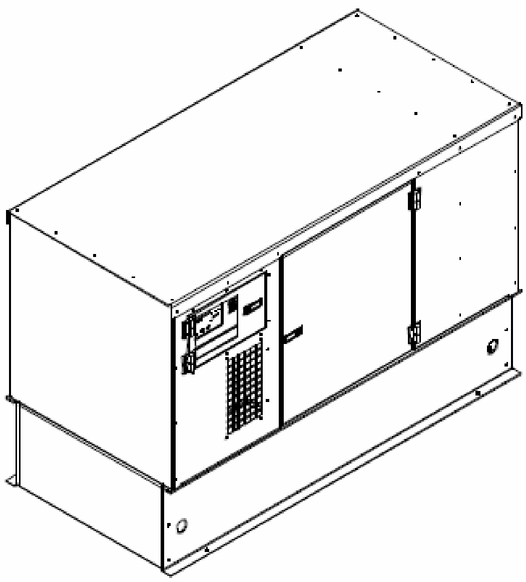
Light Towers
Load Banks
Marathon Generator Ends
PTO Generators
Racor Fuel Filters
Remote Tanks
Trailers
-1200 lb. Heavy Duty Trailer
-2000 lb. Heavy Duty Trailer
-3500 Lb. Heavy Duty Trailer with Internal Fuel Tank
-2800 lb. Heavy Duty Trailer
-2800 lb. Heavy Duty Trailer (Does Not Include Braking System)
Transfer Switches
Transformers
Voltage Regulators

ARMSTRONG POWER SYSTEMS

Model: ALO18S
Diesel Generator Set



FEATURES

- Armstrong provides one-source responsibility for the generator system and its accessories.
- All units and components are factory tested during prototype and manufacturing stages assuring long product life.
- Generator set accepts one-step 100% of full load per NFPA 110.
- A **one-year** limited **warranty** covers all systems and components. Extended warranties are available.
- Rugged 4 cycle heavy -duty diesel engine, with direct fuel injection system and swirl intake ports combine for a low fuel consumption and excellent transient response.
- **Generator features:**
  - Unique Volts per Hertz compensated electronic AVR excitation system delivers reliable voltage response for in rush loads.
  - Brushless, rotating-field generator has low reactance, 2/3 pitch, class H insulation, minimizes voltage distortion when powering non-linear loads.
- **More features:**
  - Controllers are available to meet your most demanding applications.
  - In the event of low oil pressure or high coolant temperature the self-protecting system will automatically stop the engine.

GENERATOR SET RATINGS

Model	Volt Code	Voltage	Winding Connection	Phase	Power Factor	Hz	Amps Standby	Standby kW/kVA	Prime kW/kVA
ALO18S	61	480/277	12 - HI WYE	3	0.8	60	24	16/20	14/18
ALO18S	63	440/254	12 - HI WYE	3	0.8	60	26	16/20	14/18
ALO18S	64	240/139	12 – HI DELTA	3	0.8	60	48	16/20	14/18
ALO18S	65	220/127	12 – LOW WYE	3	0.8	60	52	16/20	14/18
ALO18S	66	208/120	12 – LOW WYE	3	0.8	60	56	16/20	14/18
ALO18S	67	240/120	12 – 2 DELTA	1	1.0	60	67	16/16	14/14
ALO18S	51	415/240	12 – HI WYE	3	0.8	50	23	13/17	12/15
ALO18S	53	380/220	12 – HI WYE	3	0.8	50	25	13/17	12/15
ALO18S	55	220/127	12 – LOW WYE	3	0.8	50	43	13/17	12/15
ALO18S	57	220/110	12 – 2 DELTA	1	1.0	50	59	13/13	12/12

Stand-By ratings are continuous electrical service during the interruption of normal power. No overload capacity is specified at these ratings.
Prime ratings available with variable loads are continuous, 10% overload capacity for one hour in twelve hours periods.
Both ratings per BS 5514, DIN 6271, ISO-3046
Many industrial, commercial and residential voltages are available

ALO18S

ALTERNATOR SPECIFICATIONS

Type	Four pole, revolving field
Rotor Insulation	Class H
Temperature Rise	150°C Standby
Material	Epoxy resin
Line-To-Line Harmonic Factor (Max)	5%
Telephone Interference Factor (Tif)	1%
Voltage Regulator	Solid State
Cooling	Self-ventilated and drip proof
Bearing	1 each, pre-lubed
Coupling	Direct, Flexible Disc
Load Capacity (Standby)	100%
Overload Capacity (Prime)	110%
Voltage Regulation	
No Load To Full Load	±1 %
One Step Load Acceptance	
Per NFPA 110	100%

- Four pole, revolving field, direct coupled to engine flywheel, provides excellent alignment.
- Insulation is of class H, ready to be used on harsh environments where sea spray, sand and chemical corrosion are exis ting factors.
- Voltage regulator provides Volts/Hertz compensation to improve the motor starting capabilities, therefore support the engine handling transient loads.
- Dynamically balanced rotor, with damper winding, help dissipate transient voltage interference during load variations.
- The windings have a 2/3 pitch in order to reduce the harmonic content of voltage.
- Robust mechanical structure permits easy access to connections.

ENGINE SPECIFICATIONS

Manufacturer	Lombardini
Model	LDW 1603
Bore	3.46in. (88mm)
Stroke	3.56in. (90.4mm)
Number Of Cylinders	3
Piston Displacement	101 in.^{3} (1.65L)
Compression Ratio	22:1
Combustion System	Indirect Injection
Engine Type	In-Line – 4 Cycle
Aspiration	Nat. Aspirated
Engine Crankcase Vent System	Closed
Cylinder	Borable
Crankshaft Material	Forged Steel
Governor, Make	Mechanical
Frequency Regulation,	Lombardini
No Load To Full Load	5 %
Air Cleaner	Dry Element

- Robust, compact, heavy duty Lombardini diesel engine, for reliable endurance.
- Many various accessories available along with 4 power take-off points.
- Indirect fuel injection system with medium turbulence pre-combustion chamber reduces emissions of nitrogen oxides and particulate matter.
- Use of high precision helicoidal gears, flexible mounting of internal components, and cooling fan design reduce both mechanical and aerodynamic noise levels.
- Reduced alternating masses along with a pair of dynamic balancers aid in balancing second order alternating forces thereby reducing vibration.

STANDARD EQUIPMENT

ENGINE
- Air Cleaner
- Fuel Pump
- Fuel Filter
- Oil Pump
- Full Flow Oil Filter
- Jacket Water Pump
- Thermostat And Housing
- Exhaust Manifold Dry
- Oil Cooler
- Blower Fan & Fan Drive
- Radiator - Unit Mounted
- Electric Starting Motor 12v
- Housing & Flywheel
- Charging Alternator - 12v
- Battery Kit & Battery Rack

GENERATOR
- Synchronous, Brush-less
- Four Pole
- Single Bearing
- Direct Coupled With Flex
- Class H Insulation
- Drip-Proof Construction

CONTROL PANEL
- Digital Control Panel
- Auto Start Module
- Electric Hour Meter
- Stop-Manual-Auto Pushbuttons
- Standard Engine Control Monitoring
- Automatic Shutdowns
  * High Water Temperature
  * Low Oil Pressure
  *Protective 12vdc Circuit Breaker

-Display Lights For:
  * Water Temperature
  * Oil Pressure
  * Overcrank
  * Undercrank
  * Overspeed
  * Battery Charging

GENERAL
- Integrated Fuel Tank
- Industrial Muffler
- Rain Cap
- Lifting Points

ARMSTRONG POWER SYSTEMS

INSTALLATION AND APPLICATION DATA

	Item	Units	Type of Operation and Application			
			60 Hz		50 Hz	
			Prime	Standby	Prime	Standby
Engine	Rated Speed	rpm	1800		1500	
	Gross Engine Output	bhp (kWm)	22.5 (16.8)	24.8 (18.5)	18.8 (14)	20.8 (15.5)
	BMEP	psi (kPa)	99 (679)	113 (780)	99 (679)	109 (752)
Cooling System	Ambient Air Temperature	°F (°C)	122 (50)			
	Engine Heat Reject	BTU/min (kW)	955 (16.8)	1052 (18.5)	796 (14)	881 (15.5)
	Coolant Flow	gal/min (L/min)	15 (55)		13 (50)	
	Coolant Capacity	qt (L)	6.9 (6.5)			
	Thermostat Start to Open	°F (°C)	178 (81)			
	Thermostat Fully Open	°F (°C)	201 (94)			
	Blower Fan Diameter	in. (mm)	13.8 (350)			
Fuel System	Total Fuel Flow	gal/hr (L/hr)	25.1 (95)		26.4 (100)	
	Max. Transfer Pump Suction	ft (m)	7 (2.1)			
	Fuel Type		Diesel No.2			
	Fuel Consumption @ 25% Power	gal/hr (L/hr)	0.44 (1.67)	0.49 (1.85)	0.37 (1.40)	0.41 (1.2)
	Fuel Consumption @ 50% Power	gal/hr (L/hr)	0.76 (2.88)	0.84 (3.18)	0.64 (2.42)	0.71 (2.69)
	Fuel Consumption @ 75% Power	gal/hr (L/hr)	1.00 (3.79)	1.10 (4.16)	0.84 (3.18)	0.93 (3.52)
	Fuel Consumption @ 100% Power	gal/hr (L/hr)	1.27 (4.81)	1.40 (5.30)	1.07 (4.05)	1.18 (4.47)
Air Requirement	Radiator Fan Air Flow	ft^3/min (m^3/min)	1695 (48)		1440 (41)	
	Air Flow Restriction (After Radiator)	In.H_2O (kPa)	0.5 (0.12)			
	Engine Combustion Air Inlet Flow	ft^3/min (m^3/min)	52.9 (1.5)		42.4 (1.2)	
	Air Intake Restriction	In.H_2O (kPa)	12.8 (3.2)			
	Exhaust Temperature	°F (°C)	842 (450)		797 (425)	
	Maximun Allowable Back Pressure	In.H_2O (kPa)	44 (11)			
	Connection Outlet Size Diameter	In. (mm)	1.5 (38)			
Lubrication System	Total Engine Oil Cap. w/ Filter(s)	qt (L)	4.6 (4.4)			
	Oil Pan Capacity	qt (L)	4.0 (3.8)			
	Oil Filter Type		Cartridge			
Engine Electricals	Battery Charging Alternator	Volts, Ground	12V, negative			
	Baterry Charging Alternator	Rated amps	45			
	Starter Motor	Volts, Ground	12V, negative			
	Recommended Battery Cold Crank	CCA amps	450			
Ambient Deration	Altitude Deration 3% per 1000ft (300m) above	Ft (m)	Sea Level			
	Temperature Deration 2% per 10°F (5.5°C) above	°F (°C)	77 (25)			

ALO18S

OPTIONAL EQUIPMENT

Cooling System
- ❑ Remote Radiator
- ❑ Jacket Water Heater
- ❑ Crankcase Oil Heater

Fuel System
- ❑ Fuel/Water Separator
- ❑ Day Tank
- ❑ Above Ground Fuel Tank
- ❑ Auxiliary Fuel Pump
- ❑ Sub-Base Fuel Tank
  - ❑ Double Wall
  - ❑ UL Listed

Exhaust System
- ❑ Industrial Grade Muffler
- ❑ Residential Grade Muffler
- ❑ Critical Grade Muffler
- ❑ Super Critical Grade Muffler

Start System
- ❑ Battery Nicad
- ❑ Battery Warmer Plate
- ❑ Battery Charger
  - ❑ Automatic Float Equalizing
  - ❑ Trickle

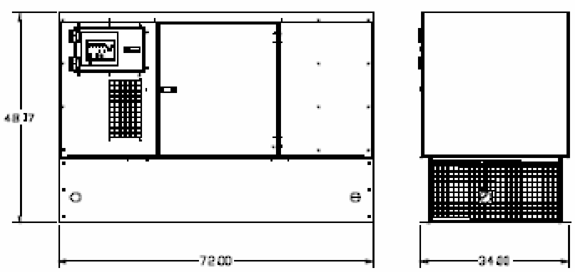
Switchgear
- ❑ Main Line Circuit Breaker
  - ❑ Shunt trip
  - ❑ Auxiliary switch
- ❑ Automatic Transfer Switch
- ❑ Paralleling
- ❑ Protective Relays

Generator
- ❑ Permanent Magnet Excitation
- ❑ Space Heaters
- ❑ Temperature Rise Detectors

Control Panel
- ❑ Emergency stop button
- ❑ Microprocessor Control Panel
- ❑ NFPA 110 Ready
- ❑ Remote Annunciation Panel
- ❑ Audible Alarm

General
- ❑ Spring vibration isolators
- ❑ Automatic Transfer Switch
- ❑ Metal Enclosure
  - ❑ Weather Resistant
  - ❑ Sound Attenuated
  - ❑ Aluminum
- ❑ Interior lights AC or DC
- ❑ Trailer
- ❑ Export Packaging
- ❑ Special Testing
- ❑ Warranties
  - ❑ ____ Year

For Other Options Consult



DIMENSIONS AND WEIGHT

	Units	Sound Att. Unit
Length	In. (mm)	72 (1830)
Width	In. (mm)	34 (864)
Height	In. (mm)	48 (1219)
Weight	Lbs (kg)	1050

General configuration for reference only, do not use these dimensions for installation purposes. Contact your local dealer for certified drawings.

ARMSTRONG POWER SYSTEMS

ARMSTRONG POWER TRADE
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Miami, FL. 33166 U.S.A.
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www.armstrongpower.com

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Sitemap

Products

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- Trucks
- Off-road
- Marine
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HYDRONIC 16
54,630 BTU/hr

Espar's Hydronic 16 Coolant Heater is typically used for the Large Coaches, Boats and Off-Road Engines. These heaters provide engine, fuel and hydraulic preheat and can be incorporated into a coaches heating system to provide supplemental heat. The first choice for those who require rapid heating when operating in "Arctic-like" climates. These heaters are available only in the 24v version only.

Features and Benefits include:

· No electrical plug-ins
· Easy start up of equipment
· Self-Diagnostics
· Supplemental cabin heat

Canada: (800) 668-5676
U.S. (800) 387-4800

Sales inquiries

Technical information, troubleshooting or application specifications

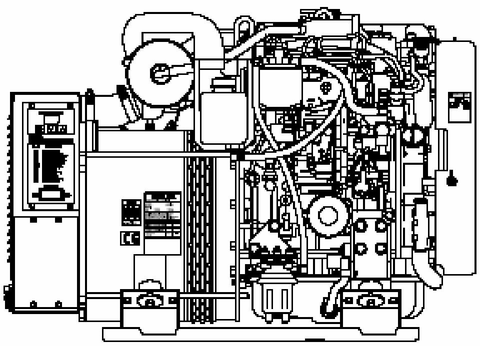
Heat Output *BTU/hr(KW)*	**Fuel Consumption** *Gal/hr (L/hr)*	**Electrical Consumption** *24 volt only*
55,000 (16)	Diesel 1, 2 or Kerosene 0.48 (1.8)	2.1 amps
Water Throughput	**Weight**	**Dimensions**
1320 US gal/hr (5000L/hr)	40 lbs. (18 kg)	L= 60 cm (24") W= 23 cm (9") H= 22 cm (8.8")

Model: 15.5EOZD 60 Hz
13EFOZD 50 Hz

KOHLER POWER SYSTEMS

1-Phase Diesel

ISO 9001 KOHLER POWER SYSTEMS NATIONALLY REGISTERED



Marine Generator Set

Engine Features

- Diesel fueled
- Three cylinder
- Four cycle
- Closed cooling system
- Heat exchanger
- Frequency regulation of ±5%
- Electric fuel lift pump
- Lifting eyes

Generator Features

- Remote start 12-pin connector
- Class H insulation
- Multivoltage adjustability
- 60/50 Hz capability
- Voltage regulation of ±1.5%
- Radio suppression

ADC 2100 Advanced Digital Control Features

- Designed for today's most sophisticated electronics
- Easy to read alpha-numeric display
- Compact, integrally mounted control
- Potted boards/sealed connectors for maximum corrosion protection
- SAE J-1939 CANbus output
- Remote monitoring of up to 13 fault conditions
- Membrane keypad for configuration and adjustment
- Programmed crank cycle

Optional Accessories

- Sound shield
- Remote digital gauge
- Siphon break
- Circuit breakers

Generator Weights and Dimensions

	Without Sound Shield	With Sound Shield
Weight, kg (lb.)		
Wet	308 (679)	344 (760)
Dry	302 (665)	338 (745)
Length, mm (in.)		
12 volt	923 (36.36)	1048 (41.25)
24 volt	936 (36.86)	
Width, mm (in.)	563 (22.17)	635 (25.00)
Height, mm (in.)	659 (25.96)	690 (27.18)

Generator Ratings

Model Series	Voltage	Hz	25°C (77°F) Amps	25°C (77°F) kW/kVA	Ph
15.5EOZD	120/240	60	129.2/64.6	15.5/15.5	1
	115/230	50	113.0/56.5	13/13	1
13EFOZD	230	50	56.5	13/13	1
	240	50	54.2	13/13	1

RATINGS: Marine continuous ratings per ISO 3046, ISO 8528-1, and Kohler ISO rating guideline 2.14. Obtain technical information bulletin (TIB-101) on ratings guidelines for complete ratings definitions.

Availability is subject to change without notice. Kohler Co. reserves the right to change the design or specifications without notice and without any obligation or liability whatsoever. Contact your local Kohler generator distributor for availability.

Application Data

Engine

Engine Specifications	60 Hz	50 Hz
Type	4 cycle, turbocharged	
Cylinder, quantity	3	
Displacement, L (cu. in.)	1.50 (91.3)	
Bore and stroke, mm (in.)	84 x 90 (3.31 x 3.54)	
Compression ratio	19.0:1	
Combustion system	Direct injection	
Rated rpm	1800	1500
Max. power at rated rpm, HP	26.1	21.8
Cylinder block material	Cast iron	
Cylinder head material	Cast iron	
Piston rings: quantity, type	2 compression/1 oil	
Crankshaft material	Forged steel	
Connecting rod material	Forged carbon steel	
Governor, type	Centrifugal, mechanical	

Engine Electrical

Engine Electrical System	60 Hz	50 Hz
Battery, voltage	12 volt (standard) 24 volt (optional)	
Battery, charging	40-amp alternator	
Battery, minimum recommendation	500 CCA, 100 amp hr.	
Starter motor	1.8 kW Bendix, gear-reduction automotive type	

Cooling

Cooling System	60 Hz	50 Hz
Capacity, L (qt.), approx.	4.4 (4.6)	
Heat exchanger type	Integral with water-cooled manifold	
Seawater pump type	Impeller type, belt driven	
Heat rejected to cooling water at rated kW, wet exhaust, kW (Btu/min.)	14.3 (813)	11.9 (677)
Engine water pump flow, Lpm (gpm)	42.8 (11.3)	30.7 (8.1)
Seawater pump flow, Lpm (gpm)	22.7 (6.0)	18.9 (5.0)

Fuel

Fuel System	60 Hz	50 Hz
Fuel shutoff solenoid	Electric	
Fuel pump	Electric, rotary vane	
Fuel pump priming	Electric	
Maximum recommended fuel lift, m (ft.)	1.2 (4.0)	

Lubrication

Lubricating System	60 Hz	50 Hz
Oil pan capacity with filter, L (qt.)	4.7 (5.0)	
Oil pump type	Pressure, trochoid pump	

Operation Requirements

Air Requirements	60 Hz	50 Hz
Engine combustion air requirements, L/min. (cfm)	1750 (62)	1460 (52)
Engine/generator cooling requirements, L/min. (cfm)	5946 (210)	4955 (175)
Fuel Consumption	**60 Hz**	**50 Hz**
Diesel, Lph (gph) at % load		
100%	5.0 (1.34)	4.3 (1.15)
75%	3.8 (1.01)	3.2 (0.85)
50%	3.6 (0.96)	2.4 (0.64)
25%	1.8 (0.48)	1.4 (0.39)

Note: The fuel consumption of the 60 Hz model is based on 15.5EOZD and the fuel consumption of the 50 Hz model is based on 13EFOZD.

Sound Data

Sound Levels	60 Hz	50 Hz
Measured at 1 meter (3.28 ft.) with a housed generator set operating at full load, dBA	67	64

Engine Features

- One-side serviceability of fuel system, lubrication system, seawater pump, and air cleaner
- Low oil pressure shutdown
- High engine temperature shutdown
- Loss of coolant shutdown
- Seawater pump impeller failure shutdown
- Focused vibromounts
- Belt guard
- Disposable oil filter
- Oil drain valve and hose
- Water-cooled turbocharger
- Air intake heater circuit for cold starting (optional)

Generator Features

- Brushless, rotating field design permits power to be obtained from stationary leads.
- Rotor and stator are vacuum impregnated and coated with high-bond epoxy varnish. Varnish helps prevent corrosion in high-humidity areas.
- Rotors are dynamically balanced to minimize vibration.
- Copper windings ensure minimal heat buildup. Insulation meets NEMA standards for class H insulation.
- Direct connected to the engine, the generator has sealed precision ball bearings with a precision-machined steel sleeve in the end bracket to prevent shaft misalignment and extend bearing life.
- Mounted on a drip-proof tray.
- Equipped with a four-lead reconnectable stator.

Application Data

ADC 2100 Control Features

- LED display:
  - Runtime hours
  - Crank cycle status
  - Diagnostics/fault codes/data
- Keypad
  - Secure access, password protected
  - Voltage, gain, and speed adjustment
  - Controller configuration (system voltage, phase, and frequency settings, battery voltage, and generator set model)
- Master control switch: run/off-reset/auto (engine start)
- Remote two-wire start/stop capability
- Potted electronics and sealed connections
- Voltage regulation $\pm 1.5\%$
- Cyclic cranking: 15 seconds on, 15 seconds off (3 cycles)
- Faults with shutdown:
  - High engine temperature
  - Low oil pressure
  - Loss of coolant
  - Overcrank safety
  - Overspeed
  - Over/under voltage
  - Over/under frequency
  - Auxiliary fault
- Faults with warning:
  - Low battery voltage
  - High battery voltage
- Power requirements:
  - 12 or 24 VDC with fuse protection
  - 200 mA @ 12VDC/100 mA @ 24 VDC

Accessories

Sound Shield

Provides for highly effective silencing, ease of access for engine/generator servicing, low maintenance, excellent durability, and safety. The sound shield's customer connection panel includes connections for the following:

- Battery (positive and negative)
- Equipment ground
- Fuel inlet and return
- Seawater inlet
- Water-cooled exhaust outlet
- Oil drain
- Customer load lead access
- Customer interface

Siphon Break

Mandatory kit on generators installed below the waterline. Prevents the siphoning of flotation water into the engine.

Line Circuit Breakers

Protect the generator from extreme overload.

Preheat Kit

Provides improved starting in cold climates.

Ship-to-Shore Switch

Allows immediate switching to Kohler® generator set power or shore power protecting the electrical system from the possibility of simultaneous connection of both power sources. Available as a three-pole ship-to-shore switch.

Remote Digital Gauge

Allows starting/stopping from a location remote from the generator set. Standard 76.2 mm (3 in.) dia. hole required for mounting.

Oil Pressure Sender Kit

Provides sender necessary to make digital gauge functional.

Remote Connection/Extension Harness

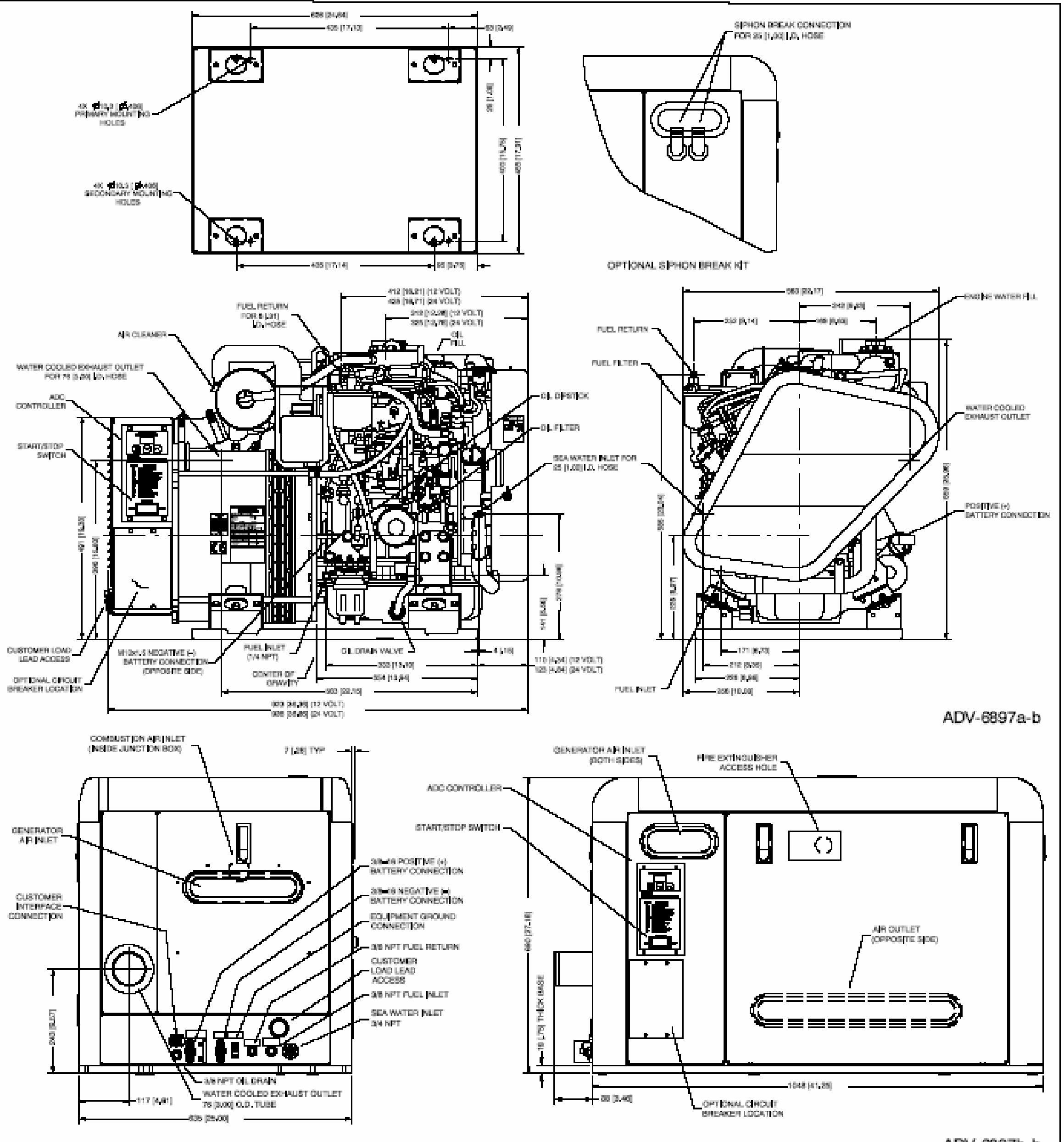
Provides wiring between the remote digital gauge and the ADC connector. Extension limited to a total of four kits and 23 m (75 ft.). Available in 4.6 m (15 ft.) and 7.6 m (25 ft.) lengths.

12-Inch Remote Wiring Harness

Equipped with a 12-pin connector on one end that connects to the standard customer interface connector. Equipped on the other end with leads for connection to customer-supplied wiring.

KOHLER POWER SYSTEMS

KOHLER CO., Kohler, Wisconsin 53044 USA
Phone 920-565-3381, Fax 920-459-1646
For the nearest sales and service outlet in the US and Canada, phone 1-800-544-2444
KohlerPowerSystems.com



DISTRIBUTED BY:

NOTE: Dimensions in [ ] are inch equivalents.

NOTE: This drawing is provided for reference only and is not intended for installation planning. Contact your local distributor for more detailed information.

G2-86 (15.5EOZD) 9/05c

GS17D - LP

Water-Cooled, Diesel Generator Set

Technical Data Sheet

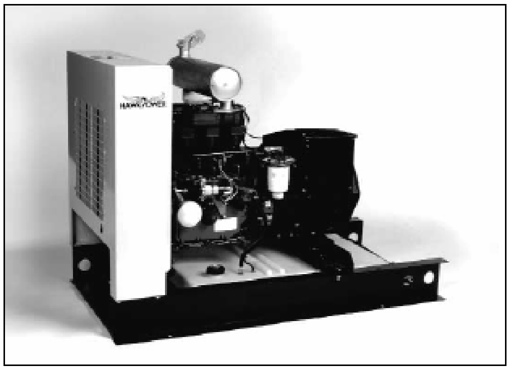


**Photo displays GS12D-LP Generator set for illustration purposes only.

Standard Genset Specification

- High Coolant Temperature Automatic Shutdown
- Radiator and Pusher Fan
- UV/Ozone Resistant Hoses
- Fan Guard
- Battery Charge Alternator
- Battery Cables
- Battery Tray and Holddown
- Vibration Isolation of Unit to Mounting Base
- Integral Base Frame
- Low Oil Pressure Automatic Shutdown
- Fuel Control Solenoid
- Mechanical Fuel Lift Pump
- 12 volt Starter Motor
- Medium-duty Air Cleaner
- Main Line Circuit Breaker
- Engine Mounted Muffler
- 22.9 U.S. Gallon (86.6 Liter) Fuel Tank with Fuel Level Gauge in Filler Cap

Generator Set Data

Model Number GS17D-LP	Stand-by	Prime	Voltage Connection
Stand-by kW (kVA) Ratings @1800 RPM			
1 PH 60 Hz, 1.0 PF	16.5 (16.5)	15.0 (15.0)	120/240
3 PH 60 Hz, 0.8 PF	16.6 (20.8)	15.1 (18.9)	227/480
Stand-by kW (kVA) Ratings @1500 RPM			
1 PH 50 Hz, 1.0 PF	12.6 (12.6)	11.5 (11.5)	110/220
3 PH 50 Hz, 0.8 PF	12.9 (16.1)	11.7 (14.6)	190/380
Consult Lister-Petter, Inc. for additional voltages.			

Stand-by Power:

Defined as power available for one hour in twelve of continuous operation. For Prime (continuous) Power rating, divide by 1.1.

De-Rating:

Power outputs shown must be adjusted for site ambient conditions as follows:

- **Altitude:** Approximately 1.5% for every 300m (1000 ft.) above 100m (325 ft.).
- **Temperature:** Approximately 1% for every 5° C (9° F) above 25° C (77° F).
- **Humidity:** Up to approximately 10%, depending on ambient temperatures.

NOTE: *These de-rate factors are approximate. For definitive specifications, consult Lister-Petter, Inc.*

Arrangement:

Close-coupled with rotor bolted to flywheel and generator flange bolted to flywheel housing. Vibration isolators are fitted between base and generator assembly.

(See drawing for dimensions).

- Plus one of the following control panels:

ES - Basic Electric Start:

Manual start/stop. This control provides safety shutdowns for low oil pressure and high engine temperature.

NOTE: *No engine gauges or AC meters are available for this control.*

BD - Basic Digital Autostart:

Set comes with a two-wire control system capable or transfer switch, or other autostart applications initiating the starting sequences from an open to close contact. Control panel includes a running time meter, three-position toggle switch with auto/off/run positions, safety shutdowns for low oil pressure, high engine temperature, overspeed and overcrank.

NOTE: *For fault indication and/or engine gauges and AC meters, use DS control.*

DS - Digital Autostart with LCD:

As Basic Digital Autostart plus LCD screen read out. Control panel includes a three-position toggle switch with auto/off/run positions, an LCD display of running time, oil pressure, water temperature and battery voltage. Fault indication provided for low oil pressure, high engine temperature, overspeed and overcrank.

Options for DS Control Panel:

1. AC meter package includes a display of AC volts, AC phase, AC amps and AC frequency
2. Remote annunciator with LCD display and audible alarm
3. Communications package
4. NFPA 110 Configuration

Genset Options

- 12 Volt Battery
- Battery Charger
- Weather Enclosure
- Coolant Heater
- Electronic Governor
- Sound Attenuation
- Heavy-duty Air Cleaner
- Export Crating
- Critical Silencer
- AC Meters

GS17D - LP

Engine Specification

Manufacturer: Lister-Petter

Model: LPW4 water-cooled industrial diesel engine

Design: Four-cycle, four-cylinder, naturally aspirated diesel with direct injection combustion, cast iron crankcase and cylinder head.

Displacement: 1.8 Liter

Bore x Stroke: 3.38 in. (86 mm) x 3.15 in. (80 mm)

Compression Ratio: 18.5 : 1

Lube Oil System: Full flow pressure lube oil system with spin-on cartridge filter with bypass.

Recommended Oil Filter change:
250 hours up to 95° F (35° C) ambient
125 hours above 95° F (35° C) ambient

Air Cleaner: Medium-duty

Fuel System: Individual fuel injection pumps operated by the camshaft. Lift of the fuel lift pump is 10 feet (3.04 m) maximum.

Engine Specifications at 60 Hz (50Hz) Rated Load

Engine Model LPW4	U.S.	Metric
Cylinder Displacement	113.5 cu. in.	1.8 liter
Exhaust Gas Flow	140.4 cfm (117.0)	66.3 l/sec. (55.2)
Exhaust Temperature	950° F	510° C
Maximum Back Pressure	20" water	52 mbar
Governor Droop	5%	
Steady-State Frequency Regulation	+/- 0.5%	
Combustion Air	50.2 cfm (41.9)	23.7 l/sec. (19.7)
Cooling Air Flow	2250 cfm (1875)	1.06 m/sec. (0.88)

Fuel Consumption 60Hz (50Hz)

Load	US Gal/Hr	Liter/Hr
100%	1.2 (1.0)	4.5 (3.8)
75%	1.0 (0.8)	3.8 (3.0)
50%	0.7 (0.6)	2.6 (2.3)

Alternator Data

Design: 4-Pole, brushless, single bearing, rotating field, solid state AVR, 4-lead dedicated, single Phase. 3 Phase, 12-lead reconnectable outputs available.

Construction: Complies with NEMA, IEEE and ANSI standards. Self-ventilated, drip-proof construction. Triple-dip varnish and epoxy-coated windings to Class H insulation with 2/3 pitch wound stator for a smooth voltage wave form.

Voltage: 60 Hertz, 1 Phase 120/240 VAC, 3 Phase 277/480 VAC.
50 Hertz, 1 Phase 110/220 VAC, 3 Phase 190/380 VAC.
Consult LPI for additional voltages.

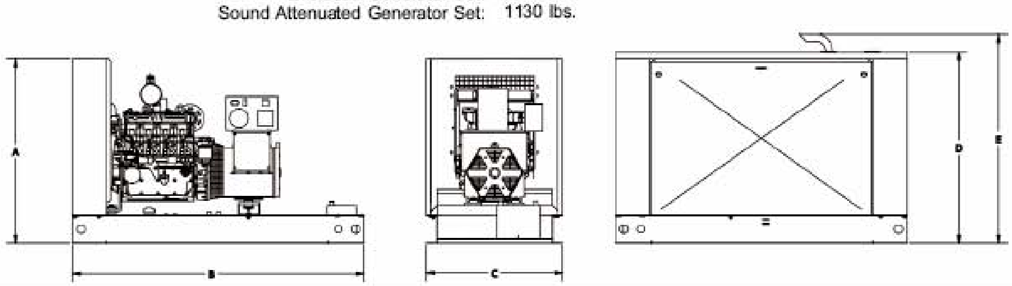
Alternator Statistics at Rated Load

Alternator Manufacturer	Newage
Voltage Change with 100% Load Step Applied	Within 3% ($\frac{1}{4}$ sec.)
Telephone Influence Factor (TIF)	Less than 50
Voltage Regulation	2% all loads to 100%
Total Harmonic Factor (THF)	Less than 2%
Temperature Rise	125° C

Approximate Weight (includes coolant and oil):

Open Generator Set: 920 lbs.
Enclosed Generator Set: 1050 lbs.
Sound Attenuated Generator Set: 1130 lbs.

A = 43.13"
B = 68.5"
C = 32.0"
D = 44.75"
E = 48.75"



Shipping Details

Crate Type	Open/Encl Length	Sound Att. Length	All Width	All Height	Open Weight	Encl. Weight	Sound Att. Weight
Pallet Only	75"	99"	37"	55"	990 lbs.	1125 lbs.	1205 lbs.
Open Crate	77"	101"	37"	59"	1065 lbs.	1200 lbs.	1280 lbs.
Enclosed Crate	77"	101"	37"	59"	1100 lbs.	1235 lbs.	1315 lbs.

For further information, contact:

The information in this data sheet is of a general nature and does not form part of any contract or warranty. We have made efforts to ensure that the information is accurate but reserve the right to amend specification and information without notice or any obligation or liability. The set illustrated is not necessarily the standard build.

HAWKPOWER

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North Wind HR3

High Reliability 3 kW Wind Energy System

Northern

Power

Systems

The North Wind® HR series of high-reliability wind turbines supply power for telecommunications, radar, pipeline control, navigational aids, cathodic protection, and water pumping in 18 countries on all seven continents. They are engineered to operate unattended in harsh environments where system availability must exceed 99%.

As a sole power source, the HR3 provides primary power for high-reliability applications having loads of up to 1000 watts continuous where wind speeds average over 6 m/s (14-15 mph). In larger capacity MicroGrid™ systems it complements photovoltaics and fuel-fired generators.

ADVANTAGES

• **Reliability.** North Wind HR series turbines have logged more than 2.5 million hours of operation--many at sites near both the North and South Poles--with system availability exceeding 99%.

• **Maintainability.** Preventive maintenance is required only once each year. Design life is 25 years. Electronic components are mounted at ground level for easy accessibility.

• **Ruggedized, Simple Design.** Engineered for substantial safety factors. The HR3 has just three moving assemblies.

• **Survivability.** Installed HR series turbines have survived winds in excess of 71 m/s (160 mph). System design loading accommodates three inches of radial ice on all parts of the machine. Ice build-up within this range does not restrict turbine rotation and blade flexibility encourages shedding. Sealed construction and weather-tight fittings are field proven.

• **Ease of Installation.** An HR3 and tower can be installed in one day without a crane. Both are readily transportable to remote sites.

• **Cost Savings.** The HR3 can provide highly reliable power without any fuel costs at remote installations. HR3 systems require much less maintenance than comparable diesel-based power systems.

FEATURES

• **Passive Rotor Control.** The HR3's Variable Axis Rotor Control System (VARCS™) includes a torsion spring against which the rotor and generator tilt to control RPM and power in any wind speed. It provides both overspeed control and a maintenance shutdown mechanism while allowing the use of a fixed pitch rotor assembly and a fixed tail assembly. The VARCS eliminates the need for a mechanical brake.

• **Field Proven Electrical System.** A direct drive, slow speed Lundel alternator eliminates the need for a gearbox. Pulse-width modulation of the alternator field provides continuous voltage regulation. The charging voltage is field adjustable within 1% to allow for the precise matching of system output to load and battery requirements.

• **High Performance Materials.** High strength alloy steel resists embrittlement and will not fracture at any temperatures encountered in nature. Construction features full penetration, stress-relieved welds. The VARCS spring is cryogenically treated to tolerate extremes of cyclic loading. Corrosion resistant materials including copper-free aluminum alloys are used throughout the turbine and have been carefully selected to prevent galvanic reactions.

• **C-Lam® Wood Composite Blades.** Combining the superior flexibility and fatigue resistance of natural wood fibers with the durability of penetrating epoxy resins and two-part urethane coatings. Leading edge protection is state of the industry and helicopter proven.

Northern Power Systems • 1 North Wind Road • Moretown, VT 05660 • Tel (802) 496-2955 • Fax (802) 496-2953

Technical Data • North Wind HR3

Performance

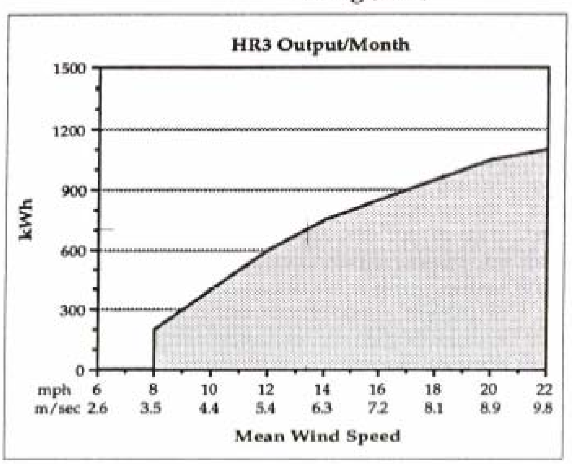
Rated Power Output	3000 Watts @ 12.5 m/s (28 mph)
Peak Output	3200 Watts @ 14.5 m/s (32.5 mph)
Cut-in Windspeed	3.6 m/s (8 mph)
Design Life	25 years
Maintenance Interval	1 Year

Wind Turbine

Rotor Configuration	Horizontal axis, upwind, 3-bladed
Rotor Diameter	5 m (16.4 ft)
Blade Material	C-Lam® wood laminate
Transmission	None required(direct drive)
Yaw Control	Free yawing
Rotor Speed Control	VARCS™
Speed Control Initiation	9.4 m/s (21 mph)
Automatic Shutdown	47 m/s (105 mph)
Maintenance Shutdown	Winch-operated cable
Total Turbine Weight	315 kg (695 lb)
Overall Turbine Length	3.44 m (11.3 ft)

Electrical System

Voltage (nominal)	24, 48, or 110 VDC; options
Generator Type	3 Ø synchronous alternator
Field Configuration	Lundel type, shunt connected
Voltage Regulation	Solid state PWM field control
Rectification	Silicon diode full-wave bridge
Lightning Protection	Faraday shielding; MOV
Regulator Housing	20" x 20" x 8", NEMA 1, 22.7 kg (50 lb)



Tower

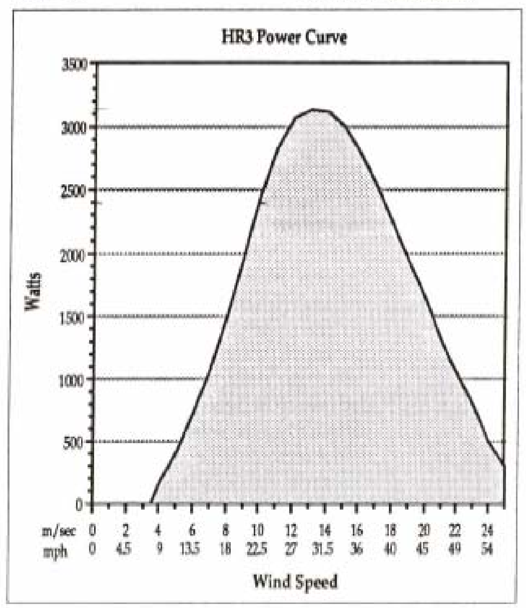
Types	Guyed; Self-Supporting
Standard Heights	12 m (40 ft) to 30 m (100 ft)
Foundation Options	Concrete piers or pads; Rock anchors
Structural Materials	High-strength steel, hot dip galvanized

Environmental Tolerances

Temperature	-60°C to +60°C (-76°F to +140°F)
Wind, Steady	54 m/s (120 mph)
Wind, Gusts	74 m/s (165 mph)
Rain, Dust, Marine	Sealed, corrosion-resistant construction

Shipping Dimensions

Turbine: 4 crates	
Total weight	399 kg (880 lbs)
Total volume	1.6 cu m (55 cu ft)
Tower (examples):	
12m (40 ft) guyed	
Weight	680 kg (1500 lbs)
Volume	3.9 cu m (137 cu ft)
18m (60 ft) self-supporting	
Weight	1,261 kg (2780 lbs)
Volume	2.8 cu m (100 cu ft)



Performance projections are based on expected wind speed distributions. Actual results may vary.
Northern Power Systems reserves the right to change or modify the design of any of its products at any time.

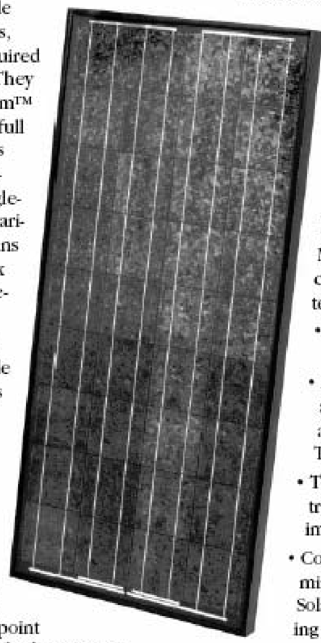
MSX-60 and MSX-64 Photovoltaic Modules

ANNIVERSARY 1973–1998

SOLAREX

The MSX-64 and -60 are among the most powerful of Solarex's Megamodule™ series, a product line which is the culmination of nearly three decades of extensive research in polycrystalline silicon photovoltaics. With over 3 amperes of current at peak power, these modules offer the most cost-effective package in the industry, and charge batteries efficiently in virtually any climate.

These modules may be used in single-module arrays or deployed in multiple-module arrays, wired in series/parallel combinations as required to meet current and voltage requirements. They are engineered under Solarex's IntegraSystem™ system integration concept, which ensures full compatibility with other Solarex subsystems and components (support hardware, regulators, etc.) and easy system assembly. As single-module arrays, they may be mounted on a variety of surfaces using optional kits or by means of user-fabricated support hardware. Solarex also offers hardware for supporting multiple-module arrays.



These modules are well-suited for virtually all applications where photovoltaics are a feasible energy source, including telecommunications systems, pumping and irrigation, cathodic protection, remote villages and clinics, and aids to navigation.

Individually Tested, Labeled and Warranted

As part of the final inspection procedure, every MSX module is tested in a solar simulator and labeled with its actual output—voltage, current, and power at maximum power point (P_{max})—at Standard Test Conditions and Standard Operating Conditions. Furthermore, the MSX-64 and -60 are covered by our industry-leading limited warranty, which guarantees:

- that no module will generate less than its guaranteed minimum P_{max} when purchased;
- at least 80% of the guaranteed minimum P_{max} for twenty years.

Contact Solarex's Marketing Department for full terms and limitations of this unparalleled warranty.

Reliable and Versatile

The Megamodule series has proved its reliability at thousands of installations in every climate on Earth. Among the features that contribute to its versatility:

Dual Voltage Capability

These modules consist of 36 polycrystalline silicon solar cells electrically configured as two series strings of 18 cells each. The strings terminate in the junction box on the module back. Shipped in 12V configuration, modules may easily be switched to 6V configuration in the field by moving leads in the junction box. This design also allows installation of bypass diodes on 18-cell strings, which can improve reliability and performance in systems with nominal voltage 24V and above.

High-Capacity Multifunction Junction Box

The size of the junction box (25 cubic inches, 411cc) and its six-terminal connection block allow most system array connections to be made right in the J-box. The box also can accommodate bypass or blocking diodes or a small regulator, which can save the expense and labor of additional boxes. The box is raintight (IP54 rated) and accepts 1/2" nominal or PG13.5 conduit or cable fittings. The standard terminals accept wire as large as AWG #10 (6mm^2); an optional terminal block accepts wire up to AWG #4 (25mm^2).

Proven Materials and Construction

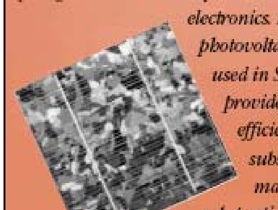
Megamodule materials reflect Solarex's quarter-century of experience with solar modules and systems installed in virtually every climate on Earth.

- Polycrystalline silicon solar cells: efficient, attractive, stable.
- Modules are rugged and weatherproof: cell strings are laminated between sheets of ethylene vinyl acetate (EVA) and tempered glass with a durable Tedlar backsheet.
- Tempered glass superstrate is highly light-transmissive (low iron content), stable, and impact-resistant.
- Corrosion-resistant, bronze-anodized extruded aluminum frame is strong, attractive, compatible with Solarex mounting hardware and most other mounting structures.

Options

- Blocking and bypass diodes
- Solarstate™ charge regulator
- Protective aluminum backplate

More than 20 years ago, Solarex made the first polycrystalline silicon solar cell, advancing photovoltaics beyond the first-generation monocrystalline technology developed for electronics. Developed specifically for photovoltaics, polycrystalline silicon is used in Solarex's Mega™ series to provide a wide range of attractive, efficient modules. They require substantially less energy to manufacture and generate substantially more energy per rated watt than other crystalline silicon modules.



630 Solarex Court, Frederick, MD 21703 USA • PHONE (301) 698-4200 • FAX (301) 698-4201 • www.solarex.com • info@solarex.com

Safety Approved

MSX-60 and -64 modules are listed by Underwriter's Laboratories for electrical and fire safety (Class C fire rating), certified by TUV Rheinland as Class II equipment, and approved by Factory Mutual Research for application in NEC Class 1, Division 2, Group C & D hazardous locations.

Quality Certified

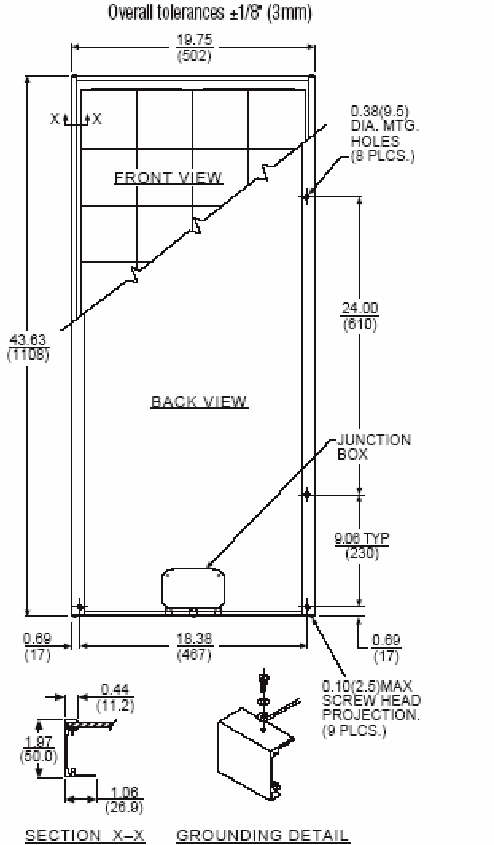
These modules are manufactured in our ISO 9001-certified factories to demanding specifications, and comply with IEC 1215, IEEE 1262 and CEC 503 test requirements, including:

- repetitive cycling between -40°C and 85°C at 85% relative humidity;
- simulated impact of one-inch (25mm) hail at terminal velocity;
- 2700 VDC frame/cell string isolation test;
- a "damp heat" test, consisting of 1000 hours of exposure to 85°C and 85% relative humidity;
- a "hot-spot" test, which determines a module's ability to tolerate localized shadowing (which can cause reverse-biased operation and localized heating);
- simulated wind loading of 125 mph (200 kph).

Mechanical Characteristics

Weight: 15.9 pounds (7.2 kg)

Dimensions: Dimensions in brackets are in millimeters
Unbracketed dimensions are in inches
Overall tolerances ±1/8" (3mm)



Typical Electrical Characteristics[1]

	MSX-64	MSX-60
Maximum power (P_{max})	64W	60W
Voltage @ P_{max} (V_{mp})	17.5V	17.1V
Current @ P_{max} (I_{mp})	3.66A	3.5A
Guaranteed minimum P_{max}	62W	58W
Short-circuit current (I_{sc})	4.0A	3.8A
Open-circuit voltage (V_{oc})	21.3V	21.1V
Temperature coefficient of open-circuit voltage	–(80±10)mV/°C	
Temperature coefficient of short-circuit current	(0.065±0.015)%/°C	
Temperature coefficient of power	–(0.5±0.05)%/°C	
NOCT[2]	47±2°C	

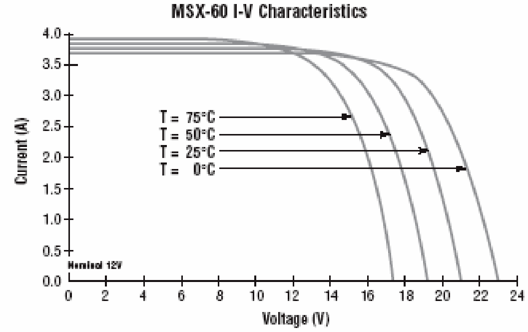
NOTES:

(1) These modules are tested, labeled and shipped in 12V configuration. These data represent the performance of typical 12V modules as measured at their output terminals, and do not include the effect of such additional equipment as diodes and cabling. The data are based on measurements made in a solar simulator at Standard Test Conditions (STC), which are:
- illumination of 1 kW/m² (1 sun) at spectral distribution of AM 1.5;
- cell temperature of 25°C or as otherwise specified (on curves).

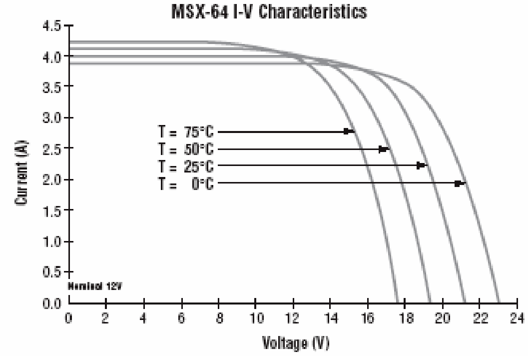
Operating characteristics in sunlight may differ slightly. To determine the characteristics of modules in 6V configuration, divide the 12V voltage characteristics by 2 and multiply current characteristics by 2. Power values are unchanged.

(2) Under most climatic conditions, the cells in a module operate hotter than the ambient temperature. NOCT (Nominal Operating Cell Temperature) is an indicator of this temperature differential, and is the cell temperature under Standard Operating Conditions: ambient temperature of 20°C, solar irradiation of 0.8 kW/m², and wind speed of 1 m/s.

MSX-60 I-V Characteristics



MSX-64 I-V Characteristics



For more information, contact:

 SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE 6059-9 11/98

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VARIABLES AFFECTING PERFORMANCE

The performance of typical MEGA SX-64 and -60 modules is described by the I-V curves and electrical characteristics table on the next page. Each module's actual, tested output characteristics are printed on its label.

The current and power output of photovoltaic modules are approximately proportional to illumination intensity. At a given intensity, a module's output current and operating voltage are determined by the characteristics of the load. If that load is a battery, the battery's internal impedance will dictate the module's operating voltage. An I-V curve is simply all of a module's possible operating points (voltage/current combinations) at a given cell temperature and light intensity. Increases in cell temperature increase current but decrease voltage.

TYPICAL ELECTRICAL CHARACTERISTICS[1]

	12 VOLT CONFIGURATION[2]	
	MSX-64	MSX-60
Typical peak power (P_p)	64W	60W
Voltage @ peak power (V_{pp})	17.5V	17.1V
Current @ peak power (I_{pp})	3.66A	3.5A
Guaranteed minimum peak power	62W	58W
Short-circuit current (I_{sc})	4.0A	3.8A
Open-circuit voltage (V_{oc})	21.3V	21.1V
Temperature coefficient of open-circuit voltage	–(80±10)mV/°C	
Temperature coefficient of short-circuit current	(0.065±0.015)%/°C	
Approximate effect of temperature on power	–(0.5±0.05)%/°C	
NOCT[3]	49°C	

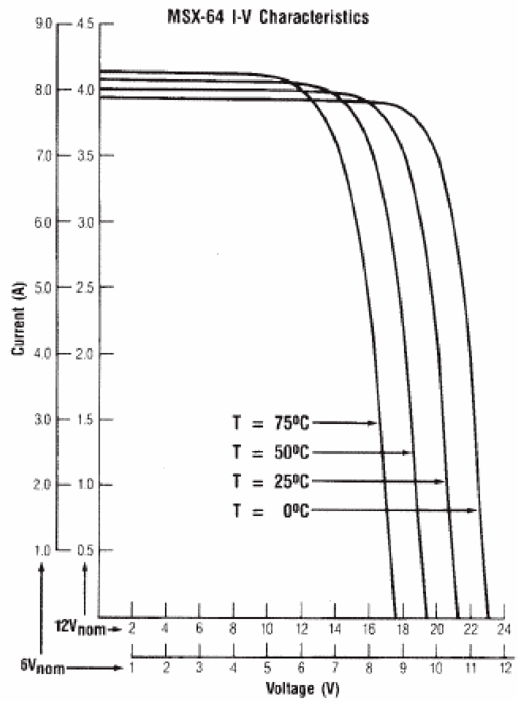
Notes:

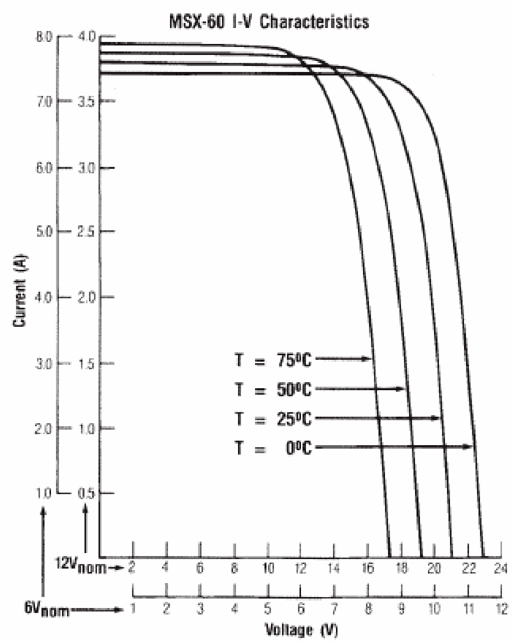
(1) These data represent the performance of typical modules as measured at their output terminals, and do not include the effect of such additional equipment as diodes and cabling. The data are based on measurements made at Standard Test Conditions (STC), which are:
- Illumination of 1 kW/m^2 (1 sun) at spectral distribution of AM 1.5
- Cell temperature of 25°C or as otherwise specified (on curves).

(2) Electrical characteristics of modules wired in the nominal 6V configuration may be found by using the 6V scales on the I-V curves. For more exact values, divide the 12V voltage characteristics in the table by 2 and multiply the 12V current characteristics by 2. Power values are unchanged.

(3) Under nearly all climatic conditions, the solar cells in an operating module are hotter than the ambient temperature, a fact which must be considered when reading module data. NOCT (Nominal Operating Cell Temperature) is an indication of this temperature rise, and is the cell temperature under Standard Operating Conditions: ambient temperature of 20°C, solar irradiation of 0.8 kW/m^2, and average wind speed of 1 m/s.

I-V CHARACTERISTICS



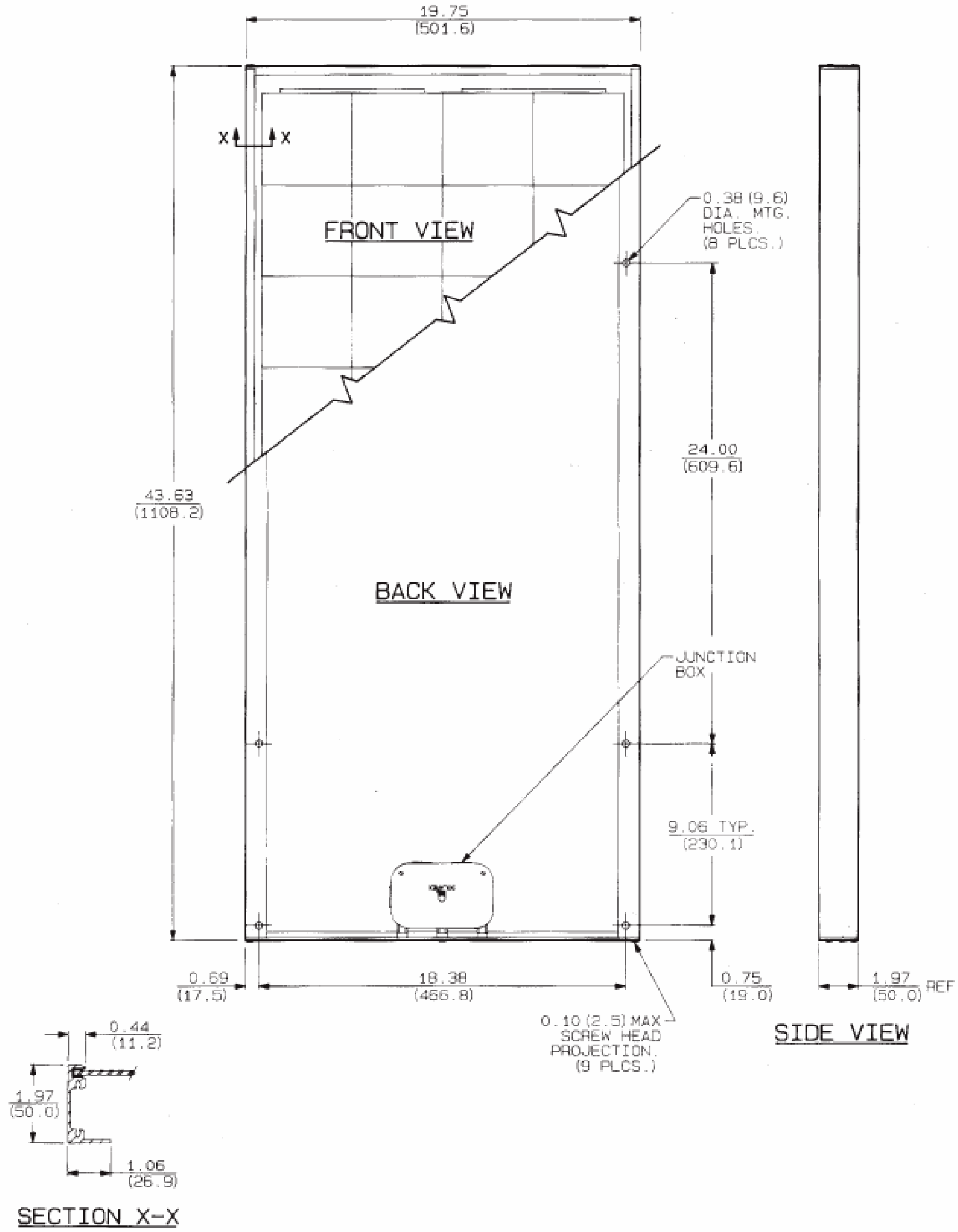


MECHANICAL CHARACTERISTICS

MEGA SX-64 and -60 are mechanically identical, differing only in electrical output.

Weight: 15.9 pounds (7.2 kg)

Dimensions: Dimensions in brackets are in millimeters
Unbracketed dimensions are in inches



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SOLAR BOOST™ 50 & 3048

MAXIMUM POWER POINT TRACKING PHOTOVOLTAIC CHARGE CONTROLLER

• The Ultimate Photovoltaic Charge Controller... Increases Charge Current Up To 30% Or More!

Patented Maximum Power Point Tracking (MPPT) technology allows Solar Boost 50 and Solar Boost 3048 to increase charge current up to 30% or more compared to conventional charge controllers. Don't waste money by throwing PV power away! Get the power you paid for with a Solar Boost charge controller.

Solar Boost controllers also provide an advanced fully automatic three stage charge control system to ensure the battery is properly and fully charged, resulting in enhanced battery performance with less battery maintenance. An equalize function is also included to periodically condition liquid electrolyte lead-acid batteries.

An optional user friendly digital display is available to monitor PV charge performance. Optional temperature compensation of charge voltage is also available to further improve charge control and battery performance.

Contact us today for more information

Visit our web site: www.blueskyenergyinc.com
email: sales@blueskyenergyinc.com
(800) 493-7877 -or- (760) 597-1642 • fax (760) 597-1731
2598 Fortune Way, Suite K • Vista, CA 92081 • USA

Get Improved Performance From Your Solar Modules and Batteries

- Patented MPPT technology increases charge current up to 30% or more!
- 50A/24V or 30A/48V ratings support large solar module arrays
- Three stage PWM charge control optimizes charge parameters to battery size & type
- MPPT power converter can charge lower voltage battery from higher voltage array
- Electronic current limit prevents overload or nuisance fuse blow
- Available digital display monitors PV charge performance
- Durable powder coat finish & conformal coated electronics resist corrosion
- Fully protected against excess current, temperature, transient voltage & polarity
- Full 36 month limited warranty, optional extended coverage available
- ETL listed to UL STD. 1741, certified to CAN/CSA STD. E335-1/2E, CE labeled

Blue Sky
ENERGY

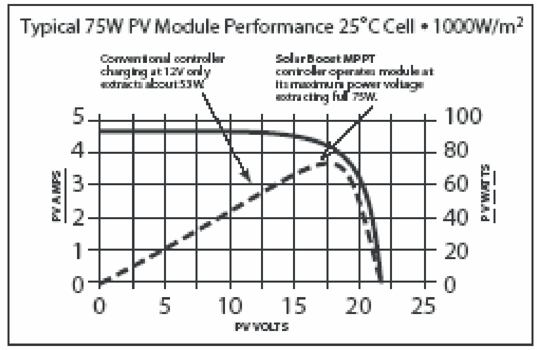
Manufactured by Blue Sky Energy Inc. and offered by a large network of quality distributors and dealers. Call us today for information or a dealer near you

Covered under one or more of the following US Patents 6,111,391 • 6,204,645

How Do Solar Boost™ Controllers Increase Charge Current?

Solar Boost controllers increase charge current by operating the PV module in a manner that allows the module to produce all the power it is capable of. A conventional charge controller simply connects the module to the battery when the battery is discharged. When the 75W module in this example is connected directly to a battery charging at 12 volts its power production is artificially limited to about 53 watts. This wastes a whopping 22 watts or nearly 30% of the available power!

Patented MPPT technology used in Solar Boost controllers operates in a very different fashion. The Solar Boost controller continually calculates the module's maximum power voltage, in this case 17 volts. It then operates the module at its maximum power voltage to extract maximum power. The higher power extracted from the module is then provided to the battery in the form of increased charge current. In conditions where extra PV power is not available, Solar Boost controllers will operate as a conventional controller with very low voltage drop.



The actual charge current increase you will see varies primarily with module temperature and battery voltage. In comfortable temperatures, current increase typically varies between 10 to 25%, with 30% or more easily achieved with a discharged battery and cooler temperatures. What you can be sure of is that Solar Boost charge controllers will deliver the highest charge current possible for a given set of operating conditions.

SPECIFICATIONS	Solar Boost 50	Solar Boost 3048
Current Rating	50 Amp Maximum	30 Amp Maximum
Nominal System Voltage	12 / 24VDC Field Selectable	24 / 48VDC Field Selectable
PV Open Circuit Voltage	57VDC Maximum	140VDC Maximum
Standby Power Consumption	30mA Typical	
Charge On Power Consumption	150 / 90mA @ 12 / 24VDC	100 / 70mA @ 24 / 48VDC
Charge Algorithm	3 stage charge. Acceptance/Float transition based on charge current matched to battery amp-hours. Can accept external shunt signal for optimal charge control with widely varying loads. Selectable for 2 stage charge.	
Acceptance Voltage Setpoint	13–16VDC / 26–32VDC	26–32VDC / 52–64VDC
Float Voltage Setpoint	0–2VDC / 0–4VDC < Acceptance	0–4VDC / 0–8VDC < Acceptance
Equalization Voltage	Acceptance + 1.0 / 2.0VDC	Acceptance + 2.0 / 4.0VDC
Voltage step-down	Can charge 12V battery from 24V Array	Can charge 24V battery from 48V Array
Temperature Compensation	Optional temperature sensor adjusts charge voltage setpoint based on measured battery temperature. Field selectable slope, −5.0mV/°C/cell (lead-acid), or −2.0mV/°C/cell (NiCd)	
Power Conversion Efficiency	97% @ 40 Amp Output	97% @ 25 Amp Output
Cabinet Dimensions	10"H x 8 3/4"W x 3 1/2"D (25.5cm x 22.6cm x 8.74cm)	
Digital Display	Available in the unit, as a remote, or both. Shows PV input current, output charge current, battery voltage, charge mode and state of charge. Remote display mounts in standard duplex box, includes 25 foot (7.6m) cable. Maximum cable length to 300 feet (91.4m).	
Digital Display Range/Accuracy	Voltmeter, 70.0VDC / ±0.30% F.S.	Ammeter, 60.0A / ±0.50% F.S.
Specified Temperature Range	0 to +40°C (Extended range −40 to +60°C, will operate but may not meet spec.– see Technical Bulletin 100206)	

• Available From

• Part Numbers & Shipping Weight

Solar Boost 50 w/o display........................ SB50L..............8 3/4 lbs..............3.98kg
Solar Boost 50 w/digital display................ SB50DL............9 lbs....................4.09kg
SB50L front panel digital display.............. SB50PDL..........2 1/2 lbs..............1.14kg
Solar Boost 3048 w/o display.................... SB3048L..........8 3/4 lbs..............3.98kg
Solar Boost 3048 w/digital display........... SB3048DL........9 lbs....................4.09kg
SB3048L front panel digital display........... SB3048PDL.....2 1/2 lbs..............1.14kg
Remote display, 25' cable........................... SB50RD25........2 lbs....................0.91kg
Battery Temp. sensor, 20' cable .... 930-0022-20.....1 lbs....................0.46kg.

As a part of our continuous improvement process specifications are subject to change without prior notice

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440-0012 C

Things *That* Work

Tested by Home Power

RV Power Products' Solar Boost™ 50 MPPT PV Charge Controller

Tested by Richard Perez & Joe Schwartz

How would you like to get 10 to 30 percent more energy out of your PV modules? This maximum power point tracking (MPPT) charge controller will do just that!

What Is Maximum Power Point Tracking?
A maximum power point tracker is similar to the transmission in an automobile. They both couple a power source to a load more effectively and efficiently. What a car's transmission does mechanically, MPPT does electrically.

All PV modules have what is known as a maximum power point. The maximum power point is where module voltage times output current equals maximum power. A PV's maximum power point is constantly changing with module temperature and solar insolation. The MPPT controller tracks that power point as it changes.

In most PVs, the maximum power point at 25°C (77°F) is at 16.5 VDC or higher, while a typical battery bank is in the 12 to 15 V range. This overhead voltage or "voltage overkill" is built into PV modules by their manufacturers to compensate for voltage loss when the modules are hot. Heating a module can cause voltage depression of over 2.5 VDC just from a 25 to 50°C (77–122°F) temperature change. Batteries also change in voltage. A fully depleted 12 volt battery will have a voltage of about 12.5 VDC while under charge. A fully recharged battery will be about 15 VDC while under charge. (These figures assume a C/20 to C/10 rate of charge. Battery temperature and age are also factors).

Both voltages are well below a PV's maximum power point.

The net effect is that PV modules spend most of their lifetime not operating at their maximum power point. There is more power to be had from the module, but we can't get at it because battery voltage, and thereby system voltage, is different from the voltage at which the PV module gives its maximum power.

The MPPT solves this problem by allowing the PV module, or PV array, to operate at its maximum power point regardless of battery voltage or module temperature. This little bit of electronic wizardry can enable a PV array to produce between 10 and 30 percent more power than it does without the MPPT. Day after day, this adds up to more energy for the system.

Documentation & Shipping
Lately we've received a heap of poorly packaged products damaged in shipping. We're happy to report that the Solar Boost 50 (SB50) was well packaged and arrived in fine shape. The manual is detailed, complete, and relatively easy to follow. It is eighteen pages long and contains wiring diagrams, tables, and more than enough illustrations.

Solar Boost 50 Features & Programming
The Solar Boost 50 model we tested, which includes a digital display, retails at US$469 and has a 36 month warranty. A model without a digital display is also available, and retails at US$389. The controller is field selectable for either 12 or 24 VDC operation. A 48 VDC model is in the works, but not yet available. The SB50 has a rated output of 50 amps at either 12 or 24 VDC.

An optional remote LCD display is available for US$109. This display is the SB50's best advertisement. It shows battery voltage, PV current into the controller, and current out of the controller. We often switch between the two current settings and walk away thinking, "man, it's like having another two modules!" Battery temperature sensors are also available for US$28.

While the Solar Boost 50's maximum power point tracking capabilities are awesome, it's also a well designed three-stage, pulse width modulated (PWM) charge controller. The Solar Boost 50 uses MOSFET transistors for efficient PWM regulation. Bulk, acceptance, and float mode set points are potentiometer based, and are fully adjustable for regulation up to 32 VDC.

For systems that are cycled on a daily basis, the float mode can be disabled, making overcharge amp-hours available to the battery. A manually initiated equalization mode is also provided. The controller is reverse-polarity protected and features an automatic current limit of 50 amps. This eliminates the nuisance tripping of breakers due to current spikes caused by edge-of-cloud effect on PV arrays.

The overall dimensions of the Solar Boost 50 are 10 by 9 by 3.5 inches (25 x 23 x 9 cm). A heat sink runs the entire height of the controller. Even at maximum output, you can comfortably keep your hand on the controller's heat sink. This is a simple indicator that the controller is running efficiently and is well designed thermally.

Installing the Solar Boost 50

Home Power's Solar Boost 50 regulates the output of sixteen BP-590 PV modules mounted on a Wattsun dual-axis tracker. BP-590s have a high peak voltage of 18.5 VDC, and are an excellent module for power point tracking. The array's 40 amp output consistently pushed the SB50's output up to its rated 50 amps.

Transmission line loss should be kept to a minimum because the SB50 uses overhead voltage to increase power into the batteries. The output of our BP array is

Solar Boost 50 Data Sheet

Outside Temp	*Solar Insolation*	*PV Voltage*	*Battery Voltage*	*Input Current*	*Output Current*	*Amps Boost*	*Watts Boost*	*% Amps Boost*	*Watts In*	*Watts Out*	*Eff %*
46.8	0.27	34.40	25.65	12.2	15.8	3.6	92.3	29.5%	419.7	405.3	96.6%
55.7	0.24	33.25	25.30	8.4	10.8	2.4	60.7	28.6%	279.3	273.2	97.8%
52.6	0.22	34.10	25.75	8.0	9.9	1.9	48.9	23.8%	272.8	254.9	93.4%
61.3	1.05	32.60	25.45	39.6	49.0	9.4	239.2	23.7%	1291.0	1247.1	96.6%
52.8	0.48	34.10	26.95	17.9	21.9	4.0	107.8	22.3%	610.4	590.2	96.7%
61.7	1.01	32.55	25.40	40.0	48.0	8.0	203.2	20.0%	1302.0	1219.2	93.6%
42.5	0.75	33.35	27.65	28.4	33.6	5.2	143.8	18.3%	947.1	929.0	98.1%
54.6	0.96	31.10	25.60	36.2	42.7	6.5	166.4	18.0%	1125.8	1093.1	97.1%
47.3	1.17	35.95	29.60	31.0	36.2	5.2	153.9	16.8%	1114.5	1071.5	96.1%
52.3	0.80	32.45	27.75	13.6	15.8	2.2	61.1	16.2%	441.3	438.5	99.3%
46.3	0.03	32.95	28.15	23.1	26.8	3.7	104.2	16.0%	761.1	754.4	99.1%
42.7	0.82	32.10	27.05	29.7	34.3	4.6	124.4	15.5%	953.4	927.8	97.3%
43.2	0.88	32.05	27.50	33.7	38.2	4.5	123.8	13.4%	1080.1	1050.5	97.3%
46.9	1.08	32.15	27.70	40.4	45.6	5.2	144.0	12.9%	1298.9	1263.1	97.2%
39.9	0.89	31.95	27.60	33.5	37.8	4.3	118.7	12.8%	1070.3	1043.3	97.5%
48.7	0.86	32.05	29.00	31.4	34.2	2.8	81.2	8.9%	1006.4	991.8	98.6%
47.2	1.10	30.75	27.40	41.7	45.4	3.7	101.4	8.9%	1282.3	1244.0	97.0%
55.0	1.11	30.80	27.90	42.3	45.8	3.5	97.7	8.3%	1302.8	1277.8	98.1%
51.9	0.97	30.95	28.15	36.8	39.8	3.0	84.5	8.2%	1139.0	1120.4	98.4%
58.9	1.04	30.10	27.15	39.5	42.7	3.2	86.9	8.1%	1189.0	1159.3	97.5%
54.0	1.02	30.20	27.60	38.5	41.2	2.7	74.5	7.0%	1162.7	1137.1	97.8%
50.7	0.71	32.55	29.55	26.2	28.0	1.8	53.2	6.9%	852.8	827.4	97.0%
					Average	4.2	112.3	15.6%	950.1	923.6	97.2%
					Minimum	1.8	48.9	6.9%	272.8	254.9	93.4%
					Maximum	9.4	239.2	29.5%	1302.8	1277.8	99.3%

run through 90 feet (27 m) of #4/0 (107 mm^2) aluminum URD cable to the power room. The negative leg is routed through a 100 mV/100 A shunt for metering, and then to the Solar Boost 50. The positive input leg runs through a 60 amp Square D breaker and is terminated at the SB50. Output from the controller goes to the positive and negative buses in the Ananda power center.

The SB50 uses an internal shunt to measure the rate of controller output charge current. When regulated current falls below approximately 1.0 amps per 100 amp-hours of battery capacity, the controller goes into float mode. Most residential battery banks experience highly variable loads during charging, depending on what appliances are being operated. The SB50 is equipped with external battery shunt sense terminals. These terminals can be wired directly to the main battery shunt. In this configuration the controller "sees" the loads and uses net battery current, rather than controller output current, as a reference point for more precise regulation.

The Solar Boost 50 is well built and a pleasure to work with. It has a full enclosure that is conduit ready, with 1/2 inch and 1 inch knockouts. The input and output terminals and circuit board are solidly mounted. And the enclosure leaves plenty of room for wire wrestling during installation.

Solar Boost 50 Performance

We have been testing the Solar Boost 50 since September of 1999. During this time, we've seen current and power boosts in the range of 5 to 29.5 percent. We measured outside ambient temperature, solar insolation (with a Li-Cor SB200 pyranometer), PV array voltage, battery voltage, input current to the Solar Boost 50, and output current from the Solar Boost 50. The high operating voltage of the BP-590 modules provide optimal conditions for the SB50 MPPT. Typical boost may be slightly lower. The table shows the measured and derived data.

The Solar Boost 50 works best when the battery voltage is low and/or the PV modules are cold. Both of these conditions are more prevalent during the winter, when we need the solar energy the most. At high battery voltage, 29.60 VDC, we measured 16.8 percent current boost. At low battery voltage, 25.45 VDC, we measured 23.7 percent boost. Power boost during the entire test varied from a low of 48.9 watts to a high of 239.2 watts. Average power boost was 112.3 watts during the entire test.

Solar insolation is the instantaneous amount of solar power striking a surface. The reference standard is 1 KW/m^2, which is also called 1 sun. We took data on the Solar Boost in a variety of sunlight conditions, including times with much less than full sun (1 KW/m^2). At 0.22 KW/m^2, the Solar Boost increased array current by 23.8 percent, from 8.0 amperes to 9.9 amperes. Similar boosts of 22 to 29.5 percent were seen during solar isolations of 0.24 KW/m^2 to 0.48 KW/m^2.

The Solar Boost 50 is a very efficient charge controller. A clue to this is that it contains no cooling fan and barely gets warm when processing well over 1 kilowatt of power. We measured a high efficiency of 99.3 percent and a low efficiency of 93.4 percent, with an average efficiency of 97.2 percent during our test. Efficiency in percent is watts out divided by watts in times 100.

If you have an array with four or more modules, you will save money by using an MPPT controller. The Solar Boost 50 is the right choice if your array output is 20 amps or more. The smaller Solar Boost 2000 *(Things that Work! HP73,* page 70) is appropriate for smaller arrays. When doing cost comparisons, bear in mind that you are buying a quality PWM controller in addition to the MPPT capability. Direct comparison is not always easy, since the Solar Boost 50 is cheaper than some non-MPPT 50–60 amp controllers, and more expensive than others.

Revolutionary

Every so often a product comes along that significantly changes the RE industry. The Solar Boost 50 is one of those products, and RV Power products is in the process of obtaining a patent on their MPPT technology. The real world performance of the Solar Boost 50 is roughly equivalent to having two extra PV modules on our tracked array. Considering that the cost of the Solar Boost is less than the cost of a single module, this controller is not only energy effective, but also cost effective. If you are not using a Solar Boost 50 MPPT charge controller in your system, you're wasting some of your expensive, PV-produced power.

Access

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OMRON'S CS1D DUPLEX PLC PROVIDES SYSTEM REDUNDANCY WHILE MAINTAINING HIGH PROCESSING SPEED

SCHAUMBURG, IL (June 25, 2003)—The new CS1D duplex programmable controller builds on the high speed and reliability of Omron's CS1 controller by adding redundancy, an essential capability for critical processes and systems. Should a problem arise in the primary CPU, the CS1D automatically switches control to the second unit within one program scan, enabling continuous operation. The down CPU can be changed out while operation continues. Redundant power supply and communication modules can be removed and replaced without interrupting control operation. Continuous operation is further enhanced by "hot swappable" I/O and specialty modules.

The CS1D is configurable as a redundant CPU only, or as a complete duplex system with redundant power supply and communication modules. Communications is automatically switched to the standby unit if a failure occurs in the primary module. The CS1D is compatible with the I/O units of the entire CS1 Series, and these units can be hot-swapped to maintain and restore the system without a costly shutdown.

-more-

The CS1D system is ideal for controlling systems that require high reliability in order to ensure vital services or avoid catastrophic financial losses, such as detention facilities, wastewater processing applications, and semiconductor fabs. It also offers valuable protection to systems that require extensive and costly restoration following a failure.

A basic CS1D system is currently available from stock at a system cost starting at $11,500.

For further information, contact Omron Electronics LLC, 1 Commerce Drive, Schaumburg, IL 60173. Tel.: 800-55-OMRON. Fax: 847-843-8081. Internet: www.info.omron.com.

Omron Electronics LLC is a leading manufacturer and provider of industrial automation and electronic component products and solutions. Offering complete automation connectivity, extensive product groups include programmable controllers, sensors, operator interfaces, machine vision sensors, timers, counters, servo motors and drives, software, switches and relays. Omron also provides system integration services and offers data collection, inspection systems, and motion systems and automation systems services and products. Omron Electronics LLC is the Western Hemisphere subsidiary of Omron Corporation, a $4 billion global leading supplier of reliable, advanced electronics and control system components and services.

# # #

Appendix E – Sample FAST Model Outputs for the STORM Turbine

Summary of Blade Loads

Load	Units	Previous Design Load	New 85m/s turbulent Wind load (parked turbine)	New 85m/s turbulent Wind load (parked turbine) Shortened blade	Comment
17: RootFxb1	kN	0.780	1.685	1.624	Blade 1 flapwise shear force at the blade root
18: RootFyb1	kN	-0.214	-.114	-.115	Blade 1 edgewise shear force at the blade root
19: RootFzb1	kN	2.569	-.08	-.06	Blade 1 axial force at the blade root
Root Shear Mag	kN	0.785	1.689	1.628	Sqr Root(Fxb1^2+Fyb1^2)
20: RootMxb1	kNm	0.128	0.096	0.098	Blade 1 edgewise moment (i.e., the moment caused by edgewise forces) at the blade root
21: RootMyb1	kNm	0.655	1.262	1.143	Blade 1 flapwise moment (i.e., the moment caused by flapwise forces) at the blade root
22: RootMzb1	kNm	0.001	.003	.002	Blade 1 pitching moment at the blade root
Root Moment Mag	kNm	0.656	1.266	1.147	Sqr Root(Mxb1^2+Myb1^2)

Summary of Shaft Loads

Load	Units	Previous Design Load	New 85m/s turbulent Wind load (parked turbine)	New 85m/s turbulent Wind load (parked turbine) Shortened blade	Comment
5: Rottorq	kNm	0.146	0	0	Rotor Torque
27: LSShftFxa	kN	2.439	5.011	4.807	Low-speed shaft thrust force (this is constant along the shaft and is equivalent to the rotor thrust force)
28: LSShftFys	kN	0.222	.125	.117	Nonrotating low-speed shaft shear force (this is constant along the shaft)
29: LSShftFzs	kN	-0.596	-.328	-.340	Nonrotating low-speed shaft shear force (this is constant along the shaft)
Shear Mag	kN	0.595	.351	.360	Sqr Root(Fys^2+Fzs^2)
32: LSSGagMys	kNm	0.650	.059	.06	Nonrotating low-speed shaft bending moment at the shaft's strain gage (shaft strain gage located by input ShftGagL)
33: LSSGagMzs	kNm	0.336	.104	.091	Nonrotating low-speed shaft bending moment at the shaft's strain gage (shaft strain gage located by input ShftGagL)
Moment Mag	kNm	0.661	.120	.109	Sqr Root(Mys^2+Mzs^2)

Summary of Yaw Loads

Load	Units	Previous Design Load	New 85m/s turbulent Wind load (parked turbine)	New 85m/s turbulent Wind load (parked turbine) Shortened blade	Comment
36: YawBrFxn	kN	2.796	5.184	4.994	Rotating (with nacelle) tower-top / yaw bearing shear force (along wind)
YawBrFyn	kN	0.504	.296	.271	Rotating (with nacelle) tower-top / yaw bearing side shear force
38: YawBrFzn	kN	-0.932	-.497	-.512	Tower-top / yaw bearing vertical force
Shear Mag	kN	2.802	5.192	5.001	Sqr Root(Fxn^2+Fyn^2)
40: YawBrMyn	kNm	1.532	2.316	2.243	Rotating (with nacelle) tower-top / yaw bearing pitch moment

Summary of Tower Loads

Load	Units	Previous Design Load	New 85m/s turbulent Wind load (parked turbine)	New 85m/s turbulent Wind load (parked turbine) Shortened blade	Comment
Tower Base Shear	kN	3.483	5.626	5.465	Square root of sum of squares of base shear forces (ignoring vertical force)
Tower Base Moment	kNm	34.967	58.70	56.76	Square root of sum of squares of base moments (ignoring twisting moment)

```
Input file for testing Crunch v2.9 with sine waves.

7 is the row with the channel titles on it (zero if no titles are
available of if titles are specified below).
8 is the row with the channel units on it (zero if no units are
available of if units are specified below).
9 is the first row of data.
0 data records will be read from each file (0 to automatically
determine which rows to read).
5.005, 599.995 are the start and end times (enter zeros if you want to
use all the data records in the file).

True        Output statistics?
False       Output modified data?
True        Tab-delimited output?  (best for spreadsheets)
"F11.4"     Numerical-output format specifier.  See manual for
limitations.
False       Output aggregate analysis files?  False for separate
analysis files for each input file.
"Aggregate" is the root name of the aggregate files, if aggregates were
specified above.

0 columns in each input file.
0 columns will be used.
Format for column info is: Col_Title(10 char max), Units(10 char max),
Orig_Col_#, Scale, Offset

0 of the output columns are to be modified by the IIR filter.  Next
four lines ignored if zero.
0
0 is the type of filter (1-LowPass, 2-HighPass, 3-BandPass)
0.0 is the low cutoff frequency (ignored for low-pass filters)
0.0 is the high cutoff frequency (ignored for high-pass filters)

55 new calculated channels will be generated.
1234567890 is the integer seed for the random number generator (-
2,147,483,648 to 2,147,483,647)
Format for column info is: Col_Title(10 char max), Units(10 char max),
Equation.  Put each field in double quotes.
"Abs"," ", "Abs(C1)"
"Abs","(m/sec) ", "Abs(C2)"
"Abs"," (deg)", "Abs(C3)"
"Abs","(rpm)", "Abs(C4)"
"Abs","(kN·m)", "Abs(C5)"
"Abs","(kN·m)", "Abs(C6)"
"Abs","(kW)", "Abs(C7)"
"Abs","(-)", "Abs(C8)"
"Abs","(-)", "Abs(C9)"
"Abs","(deg)", "Abs(C10)"
"Abs","(deg)", "Abs(C11)"
"Abs","(deg/sec)", "Abs(C12)"
"Abs","(m)", "Abs(C13)"
"Abs","(m)", "Abs(C14)"
"Abs","(m)", "Abs(C15)"
"Abs","(m)", "Abs(C16)"
"Abs","(kN)", "Abs(C17)"
"Abs","(kN)", "Abs(C18)"
```

```
"Abs","(kN)", "Abs(C19)"
"Abs","(kN·m)", "Abs(C20)"
"Abs","(kN·m)", "Abs(C21)"
"Abs","(kN·m)", "Abs(C22)"
"Abs","(kN·m)", "Abs(C23)"
"Abs","(kN·m)", "Abs(C24)"
"Abs","(kN·m)", "Abs(C25)"
"Abs","(kN·m)", "Abs(C26)"
"Abs","(kN)", "Abs(C27)"
"Abs","(kN)", "Abs(C28)"
"Abs","(kN)", "Abs(C29)"
"Abs","(kN·m)", "Abs(C30)"
"Abs","(kN·m)", "Abs(C31)"
"Abs","(kN·m)", "Abs(C32)"
"Abs","(kN·m)", "Abs(C33)"
"Abs","(kN·m)", "Abs(C34)"
"Abs","(kN·m)", "Abs(C35)"
"Abs","(kN)", "Abs(C36)"
"Abs","(kN)", "Abs(C37)"
"Abs","(kN)", "Abs(C38)"
"Abs","(kN·m)", "Abs(C39)"
"Abs","(kN·m)", "Abs(C40)"
"Abs","(m)", "Abs(C41)"
"Abs","(m)", "Abs(C42)"
"Abs","(m)", "Abs(C43)"
"Abs","(kN)", "Abs(C44)"
"Abs","(kN)", "Abs(C45)"
"Abs","(kN·m)", "Abs(C46)"
"Abs","(kN·m)", "Abs(C47)"
"Abs","(kN·m)", "Abs(C48)"
"Magbldshear","(kN)", "SQRT(c17^2+c18^2)"
"Magbldmom"  ,"(kNm)", "SQRT(c20^2+c21^2)"
"Magshftshear","(kN)", "SQRT(c28^2+c29^2)"
"Magshftmom","(kN)", "SQRT(c32^2+c33^2)"
"Magyawshear","(kN)", "SQRT(c36^2+c37^2)"
"Magtowshear","(kN)", "SQRT(c44^2+c45^2)"
"Magtowmom","(kN)", "SQRT(c46^2+c47^2)"

0 channels will have moving averages generated for them.
Format for moving-average info is: "Title" (10 char max), channel #,
averaging period

1 is the Time column.
0 is the primary wind-speed column (used for mean wind speed and
turbulence intensity, 0 for none)

0 pair(s) of channels will have load roses generated for them.
Format for column info is: Rose_Title(8 char max), 0 degree load, 90
degree load, # sectors

0 columns are to be azimuth averaged.  Next four lines ignored if 0.
3
360 is the number of azimuth bins.
2 is the azimuth column.
True        Output azimuth averages to a file?

0 pairs of columns will have their crosstalk removed.
```

```
Format for crosstalk info is: OutCol #1, OutCol #2, XT(1,1), XT(1,2),
XT(2,1), XT(2,2).

0 of the output columns are to be modified by the peak finder.  Next
line ignored if zero.
0

0 channels will have their peaks and/or valleys listed to a file.  Next
three lines ignored if zero.
1           Method of identifying peaks (1: slope change, 2:
thresholds)
True  Include the time in the peak-list file(s)?
Format for peak-list info is: Channel, WriteTroughs?, Trough Thresh.,
WritePeaks?, Peak Thresh.

0 of the output columns will have PDFs generated for them.  Next two
lines ignored if zero.
20 is the number of bins.
Format for column info is: Column #, Minimum, Maximum.  If Min=Max=0,
autocalculate them.

0 of the output columns will have rainflow cycle counts generated for
them.  Next six lines ignored if zero.
1 second is the rainflow counting period.
False       Normalize rainflow cycle counts by bin width?
True        For bins with zero counts, output a space if we are using
tab-delimited output?
10 is the number of rainflow range bins.  Use "0" to output the actual
cycles instead of binned cycles.
1 is the number of rainflow means bins.  Use "1" to output ranges only.
Format for column info is: Column #, Half-Cycle Multiplier, Max Range,
Min Mean, Max Mean.

0 groups of parameters will have their extreme events recorded.  Next
line ignored if zero.
Format for column info is: Group_Title(100 char max), #ExtCols,
ColList(#ExtCols long), #InfCols(may be 0), ColList(#InfCols long)

0 of the output columns will have statistics put in separate summary
files.  Next line ignored if zero.
0

0 of the output columns will have their statistics extrapolated.
Format for statistics info is: Col_#,  Hours_to_extrapolate_to,
Quantile desired

1 input files to read:
stormpt85dcturbs.out
```

"Statistics generated by Crunch (v2.91, 11-Mar-2004) on 16-Mar-2006 at 09:58:09."

"These statistics for ""stormpt85dcturbs.out"" were based upon 54091 records."
The peak-finding algorithm was not used.

```
Parameter   Parameter   Units Minimum     Mean  Maximum     MaxRange
      StandDev    Skewness    Kurtosis    MeanXFreq
Time  (sec)       5.005 302.5 599.995     594.99      171.7636    0
      -1.2001     0.0017
HorWindV    (m/sec)           79.16 84.9934     91.06 11.9  1.6343
      0.0738      0.0086      1.0824
HorWndDir   (deg)       -2.909      0.0009      2.626 5.535 0.7091
      -0.0116     -0.0658     1.7934
RotSpeed    (rpm)       0     0     0     0     0     0     0     0
RotTorq     (kN?m)            0.207 0.2391      0.277 0.07  0.0096
      0.124 -0.1566     2.143
GenTq (kN?m)            0     0     0     0     0     0     0     0
RotPwr      (kW)        0     0     0     0     0     0     0     0
TipSpdRat   (-)         0     0     0     0     0     0     0     0
rotcp (-)         0     0     0     0     0     0     0     0
YawPzn      (deg)       -5.885      1.037 8.983 14.868      2.087
      0.1383      0.067 0.8404
NacYawErr   (deg)       -9.375      -1.0361     6.637 16.012
      2.0867      -0.1007     0.0437      1.0656
NacYawV     (deg/sec)         -37.69      -0.0017     42.21 79.9
      10.9288     0.0285      0.0232      1.7715
TipDxb1     (m)         0.099 0.1234      0.142 0.043 0.006 -0.2551
      0.1135      1.7497
TipDyb1     (m)         -0.011      -0.0094     -0.008      0.003
      0.0005      -0.0834     -0.7721     1.5681
TipDxb2     (m)         0.109 0.1266      0.144 0.035 0.0047
      0.0504      -0.0022     1.6623
TipDxb3     (m)         0.106 0.1262      0.146 0.04  0.0053      0.038
      0.0257      1.8253
RootFxb1    (kN)        1.253 1.4598      1.685 0.432 0.0566
      0.0517      0.0333      1.2639            1.688851977 blade root
shear mag : Sqrt(RootFxb1^2 + RootFyb1^2)
RootFyb1    (kN)        -0.181      -0.143      -0.114      0.067
      0.0089      -0.3804     0.1624      1.7093
RootFzb1    (kN)        -0.127      -0.1041     -0.08 0.047 0.0065
      0.0698      0.0479      1.5194
RootMxb1    (kN?m)            0.061 0.0776      0.096 0.035 0.0043
      0.2827      0.1588      2.4657            1.26564608  blade root
shear mag : Sqrt(RootMxb1^2 + RootMyb1^2)
RootMyb1    (kN?m)            0.916 1.0979      1.262 0.346 0.045 -
0.0493      0.0903      1.3849
RootMzb1    (kN?m)            0.001 0.0019      0.003 0.002 0.0003
      -2.313      8.5713      0.4303
RootMxb2    (kN?m)            0.082 0.0926      0.105 0.023 0.0031
      0.1407      0.0131      2.938
RootMyb2    (kN?m)            0.951 1.1094      1.266 0.315 0.0421
      0.0662      0.0106      1.3866
RootMxb3    (kN?m)            0.046 0.0591      0.074 0.028 0.0037
      0.1908      -0.0106     3.2909
```

RootMyb3 (kN?m) 0.967 1.1182 1.292 0.325 0.0431
0.1149 0.0232 1.4135
LSShftFxa (kN) 3.756 4.3643 5.011 1.255 0.1757
0.0879 0.0894 0.916
LSShftFys (kN) -0.13 -0.0074 0.125 0.255 0.0295 -
0.0389 0.1302 1.9329 0.351011396 shaft shear mag :
Sqr Root(LSShftFys^2+LSShftFzs^2)
LSShftFzs (kN) -0.424 -0.3836 -0.328 0.096
0.0109 0.1418 0.1448 3.6237
LSSTipMys (kN?m) -0.198 -0.0486 0.055 0.253
0.0288 -0.2342 0.1979 2.7195
LSSTipMzs (kN?m) -0.111 -0.0083 0.105 0.216
0.0285 0.0952 0.01 2.3127
LSSGagMys (kN?m) -0.195 -0.0448 0.059 0.254
0.0289 -0.2342 0.1973 2.7144 0.119570063
shaft moment mag : Sqr Root(LSSGagMys^2+LSSGagMzs^2)
LSSGagMzs (kN?m) -0.11 -0.0084 0.104 0.214 0.0282
0.0953 0.0093 2.2976
LSSGagMya (kN?m) -0.195 -0.0448 0.059 0.254
0.0289 -0.2342 0.1973 2.7144
LSSGagMza (kN?m) -0.11 -0.0084 0.104 0.214 0.0282
0.0953 0.0093 2.2976
YawBrFxn (kN) 3.525 4.4114 5.184 1.659 0.2158
0.0376 0.1261 1.0269 5.192443741 yaw shear
mag : Sqr Root(YawBrFxn^2+YawBrFyn^2)
YawBrFyn (kN) -0.295 -0.0078 0.296 0.591 0.0723
-0.0394 0.0679 1.8051
YawBrFzn (kN) -0.597 -0.55 -0.497 0.1 0.0137
0.1006 -0.0584 3.785
YawBrMxn (kN?m) 0.12 0.2425 0.365 0.245 0.0314
0.0579 0.0171 1.9497
YawBrMyn (kN?m) 1.61 1.9864 2.316 0.706 0.0936
-0.0712 0.1586 1.3765
YawBrTDxp (m) 0.333 0.4525 0.557 0.224 0.0268 -
0.0028 0.166 1.0992
YawBrTDyp (m) -0.076 0.0033 0.083 0.159 0.0228
0.0029 -0.0595 0.9177
YawBrTDzp (m) 0.013 0.0235 0.035 0.022 0.0027
0.1927 0.167 1.0858
TwrBsFxt (kN) 2.972 4.3476 5.546 2.574 0.299 -0.0131
0.1777 1.3295 5.625599079 Tower base shear mag :
Sqr Root(TwrBsFxt^2+ TwrBsFyt ^2)
TwrBsFyt (kN) -0.822 0.0712 0.943 1.765 0.2458
-0.0075 -0.0457 1.2219
TwrBsMxt (kN?m) -9.147 -0.5187 8.121 17.268
2.4427 0.0004 -0.0547 0.9933 58.70443119
Tower base moment mag : Sqr Root(TwrBsMxt^2+ TwrBsMyt^2)
TwrBsMyt (kN?m) 33.5 46.6595 58.14 24.64 2.9109
-0.0075 0.1712 1.1295
TwrBsMzt (kN?m) -0.003 0 0.003 0.006 0.0009
0.0337 -0.0229 0.9832
Abs Abs 5.005 302.5 599.995 594.99 171.7636 0
-1.2001 0.0017
Abs Abs (m/sec) 79.16 84.9934 91.06 11.9 1.6343
0.0738 0.0086 1.0824
Abs Abs (deg) 0 0.5688 2.909 2.909 0.4234
0.9621 0.8272 2.6001

Abs Abs (rpm) 0 0 0 0 0 0 0 0

Abs Abs (kN?m) 0.207 0.2391 0.277 0.07 0.0096 0.124
-0.1566 2.143
Abs Abs (kN?m) 0 0 0 0 0 0 0 0

Abs Abs (kW) 0 0 0 0 0 0 0 0

Abs Abs (-) 0 0 0 0 0 0 0 0

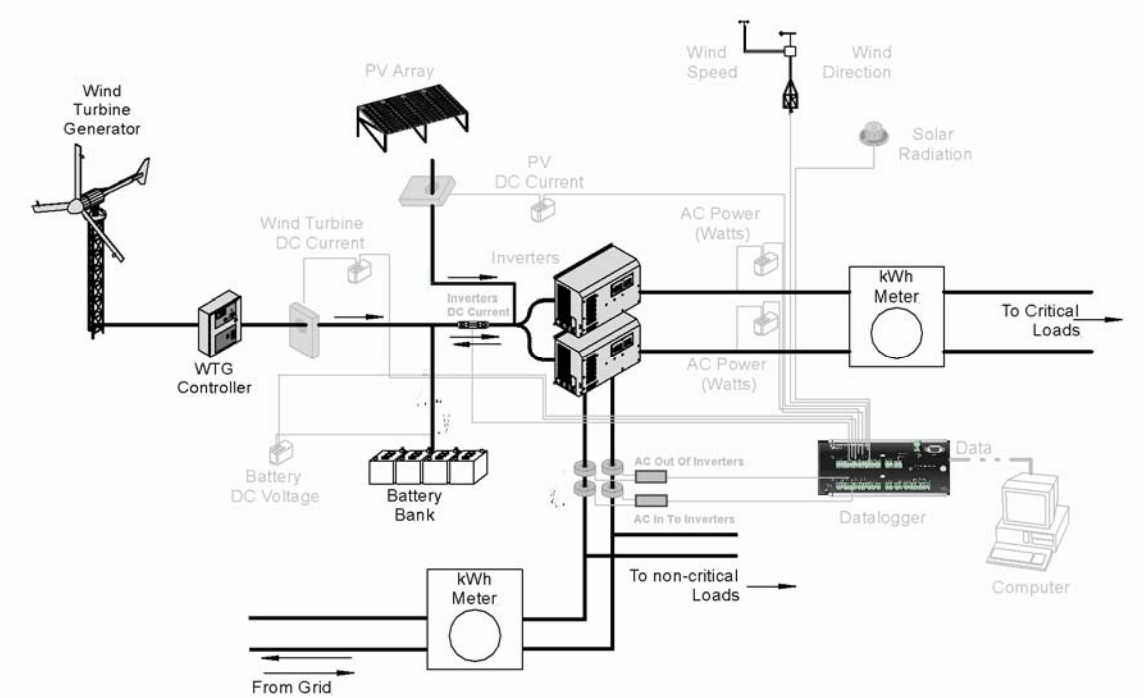
Abs Abs (-) 0 0 0 0 0 0 0 0

Abs Abs (deg) 0 1.8395 8.983 8.983 1.4308 1.0629
0.9932 1.0622
Abs Abs (deg) 0 1.8489 9.375 9.375 1.4175 1.03
0.9898 1.3513
Abs Abs (deg/sec) 0 8.6716 42.21 42.21 6.6515
0.9921 0.7738 2.4892
Abs Abs (m) 0.099 0.1234 0.142 0.043 0.006 -0.2551
0.1135 1.7497
Abs Abs (m) 0.008 0.0094 0.011 0.003 0.0005 0.0834
-0.7721 1.5681
Abs Abs (m) 0.109 0.1266 0.144 0.035 0.0047 0.0504
-0.0022 1.6623
Abs Abs (m) 0.106 0.1262 0.146 0.04 0.0053 0.038
0.0257 1.8253
Abs Abs (kN) 1.253 1.4598 1.685 0.432 0.0566 0.0517
0.0333 1.2639
Abs Abs (kN) 0.114 0.143 0.181 0.067 0.0089 0.3804
0.1624 1.7093
Abs Abs (kN) 0.08 0.1041 0.127 0.047 0.0065 -0.0698
0.0479 1.5177
Abs Abs (kN?m) 0.061 0.0776 0.096 0.035 0.0043
0.2827 0.1588 2.4657
Abs Abs (kN?m) 0.916 1.0979 1.262 0.346 0.045 -0.0493
0.0903 1.3849
Abs Abs (kN?m) 0.001 0.0019 0.003 0.002 0.0003 -
2.313 8.5713 0.4303
Abs Abs (kN?m) 0.082 0.0926 0.105 0.023 0.0031
0.1407 0.0131 2.938
Abs Abs (kN?m) 0.951 1.1094 1.266 0.315 0.0421
0.0662 0.0106 1.3866
Abs Abs (kN?m) 0.046 0.0591 0.074 0.028 0.0037
0.1908 -0.0106 3.2909
Abs Abs (kN?m) 0.967 1.1182 1.292 0.325 0.0431
0.1149 0.0232 1.4135
Abs Abs (kN) 3.756 4.3643 5.011 1.255 0.1757 0.0879
0.0894 0.916
Abs Abs (kN) 0 0.024 0.13 0.13 0.0186 1.061 1.1251
2.6337
Abs Abs (kN) 0.328 0.3836 0.424 0.096 0.0109 -0.1418
0.1448 3.6237
Abs Abs (kN?m) 0 0.0494 0.198 0.198 0.0274
0.4766 0.0637 2.7043
Abs Abs (kN?m) 0 0.0238 0.111 0.111 0.0178
0.9346 0.6176 3.1312

Abs Abs (kN?m) 0 0.0459 0.195 0.195 0.027 0.5429
0.1027 2.7144
Abs Abs (kN?m) 0 0.0236 0.11 0.11 0.0176
0.9327 0.6109 3.1127
Abs Abs (kN?m) 0 0.0459 0.195 0.195 0.027 0.5429
0.1027 2.7144
Abs Abs (kN?m) 0 0.0236 0.11 0.11 0.0176
0.9327 0.6109 3.1127
Abs Abs (kN) 3.525 4.4114 5.184 1.659 0.2158 0.0376
0.1261 1.0269
Abs Abs (kN) 0 0.0578 0.296 0.296 0.0441 1.0419
1.0506 2.5615
Abs Abs (kN) 0.497 0.55 0.597 0.1 0.0137 -0.1006 -
0.0584 3.785
Abs Abs (kN?m) 0.12 0.2425 0.365 0.245 0.0314
0.0579 0.0171 1.9497
Abs Abs (kN?m) 1.61 1.9864 2.316 0.706 0.0936 -
0.0712 0.1586 1.3765
Abs Abs (m) 0.333 0.4525 0.557 0.224 0.0268 -0.0028
0.166 1.0992
Abs Abs (m) 0 0.0184 0.083 0.083 0.0139 0.9478
0.6353 1.3076
Abs Abs (m) 0.013 0.0235 0.035 0.022 0.0027 0.1927
0.167 1.0858
Abs Abs (kN) 2.972 4.3476 5.546 2.574 0.299 -0.0131
0.1777 1.3295
Abs Abs (kN) 0 0.2042 0.943 0.943 0.1543 0.95
0.6639 1.7009
Abs Abs (kN?m) 0 1.9904 9.147 9.147 1.508 0.9497
0.6498 1.39
Abs Abs (kN?m) 33.5 46.6595 58.14 24.64 2.9109 -
0.0075 0.1712 1.1295
Abs Abs (kN?m) 0 0.0006 0.003 0.003 0.0006 0.542
-0.3266 1.9463
Magbldshea (kN) 1.2612 1.4668 1.6934 0.4321
0.0568 0.0541 0.0298 1.2622
Magbldmom (kNm) 0.9191 1.1007 1.2648 0.3456
0.045 -0.0458 0.0865 1.4118
Magshftshe (kN) 0.3306 0.3848 0.4347 0.1041
0.0112 -0.0509 0.1984 3.5649
Magshftmom (kN) 0 0.0549 0.21 0.21 0.0264
0.5923 0.4102 2.7463
Magyawshea (kN) 3.5289 4.412 5.184 1.6551 0.2158
0.0381 0.1246 1.0303
Magtowshea (kN) 3.0124 4.3551 5.5549 2.5424
0.2984 -0.0017 0.1583 1.3143
Magtowmom (kN) 33.7588 46.7267 58.1967 24.4379
2.9045 0.0026 0.1543 1.1244

Appendix F – Sample Summary Report for Power System Monitoring

Monthly Data Reports
Manzanita Tribe Activities Center Hybrid System
Boulevard, California
November 2004



The PV array continues to be generate energy well below expectations. The array is rated at 1200 watts at 1000 W/m^2 and 25 ^oC cell temperature. Although there is no measurement of the cell temperature, if we assume an extreme case of cell temperaure at 65 ^oC, and efficiency degradation at maximum power point of 0.5% per ^oC, the power output should be about 20% lower than rated, or 960 watts at 1000 W/m^2. Most of our measurements are clustered about 650 watts at 1000 W/m^2. Another frequently-overlooked cause of low PV output is the lack of maximum power-point tracking. The rule of thumb performance degradation of 0.5% per ^oC only applies to systems using perfect maximum power point tracking. When operated at a fixed voltage, as is the case at Manzanita, the performance degradation due to temperature can be much worse. Theoretical analysis of this array indicates that the lack of maximum power point tracking should only account for about a 5% loss in production, but without a short-term test of the array using a curve tracer, it is difficult to be certain if this is accurate.

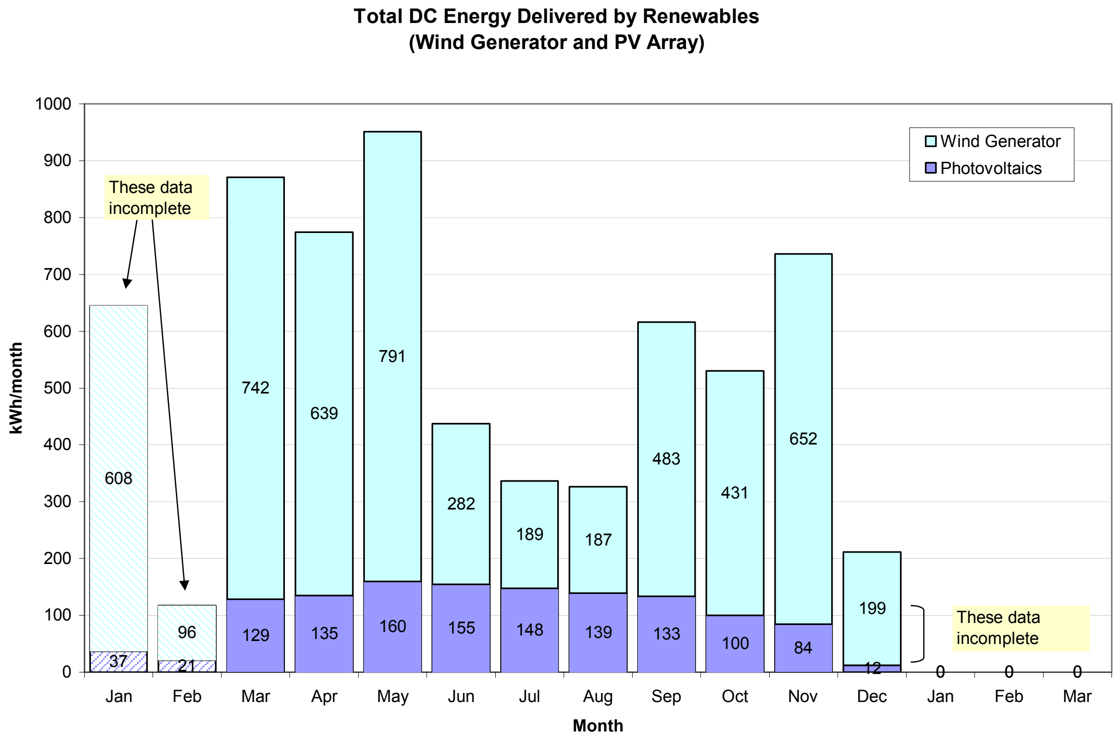
Due to a problem with the wind generator controller, the wind generator was not operating between September 25 and October 17. Starting on October 18 the wind generator returned to normal operation.

An Excel spreadsheet has been developed for summarizing the measurement results in tabular and graphical form. The following pages contain excerpts from that spreadsheet. All data presented represent measured values post-corrected for thermal offset of current transducers and an assumed PV array azimuth of 45 deg West of true South.

In the table below, entries with a blue background represent months for which the data is either unreliable, missing, or not yet available. A yellow background represents data for which a complete month does not yet exist. We expect to have no missing data from the beginning of March 2004 through the end of this contract.

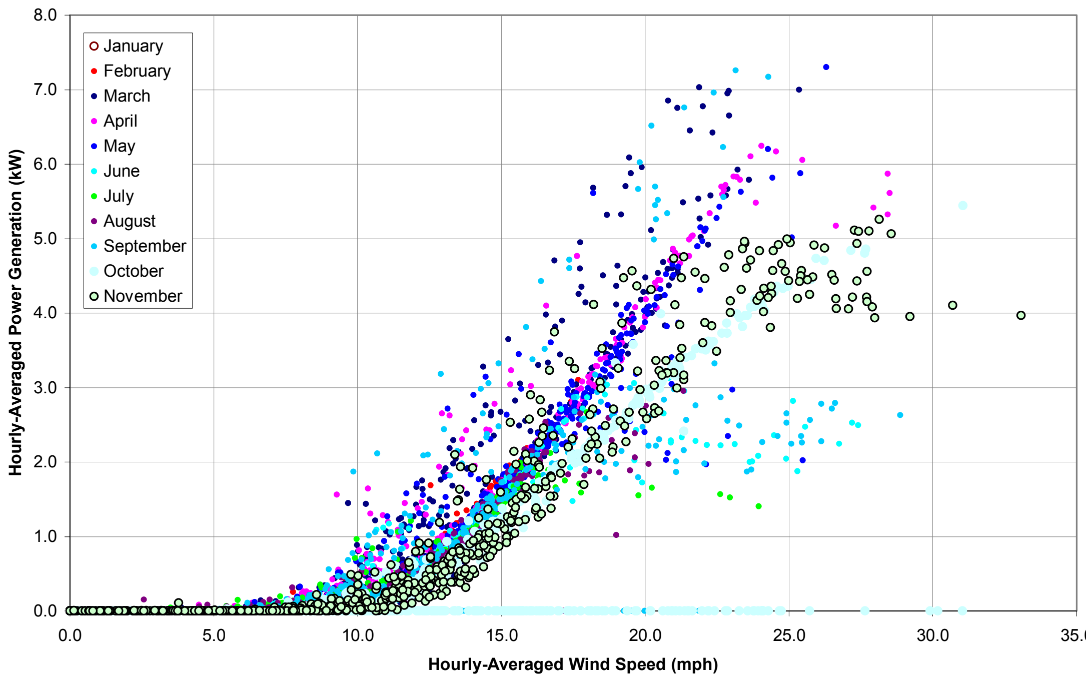
Year	Month	DC Energy Generated by Wind Generator (kWh)	DC Energy Generated by Photovoltaics (kWh)	DC Energy Generated by Renewables (kWh)	AC Energy Generated by Renewables (kWh)	AC Energy Not Used by Critical Loads (kWh)	Overall System Efficiency (%)
TOTAL ===>		**3313**	**1028**	**4341**	**3442**	**2456**	**79.3%**
2004	Jan '04	608	37	644	551	0	85.5%
2004	Feb '04	96	21	117	55	43	47.0%
2004	Mar '04	742	129	871	711	533	81.6%
2004	Apr '04	639	135	774	645	456	83.3%
2004	May '04	791	160	951	811	628	85.2%
2004	Jun '04	282	155	437	334	231	76.4%
2004	Jul '04	189	148	337	232	134	68.9%
2004	Aug '04	187	139	326	211	123	64.7%
2004	Sep '04	483	133	616	488	348	79.3%
2004	Oct '04	431	100	530	412	231	77.6%
2004	Nov '04	652	84	736	603	440	82.0%
2004	Dec '04	199	12	211	180	94	85.3%
2005	Jan '04	0	0	0	0	0	#N/A
2005	Feb '04	0	0	0	0	0	#N/A
2005	Mar '04	0	0	0	0	0	#N/A

"Critical loads" represent those loads which are fed by the inverter and which therefore will not lose power if the grid power goes down. "Non-critical loads" are all other AC loads (not fed by the inverter).

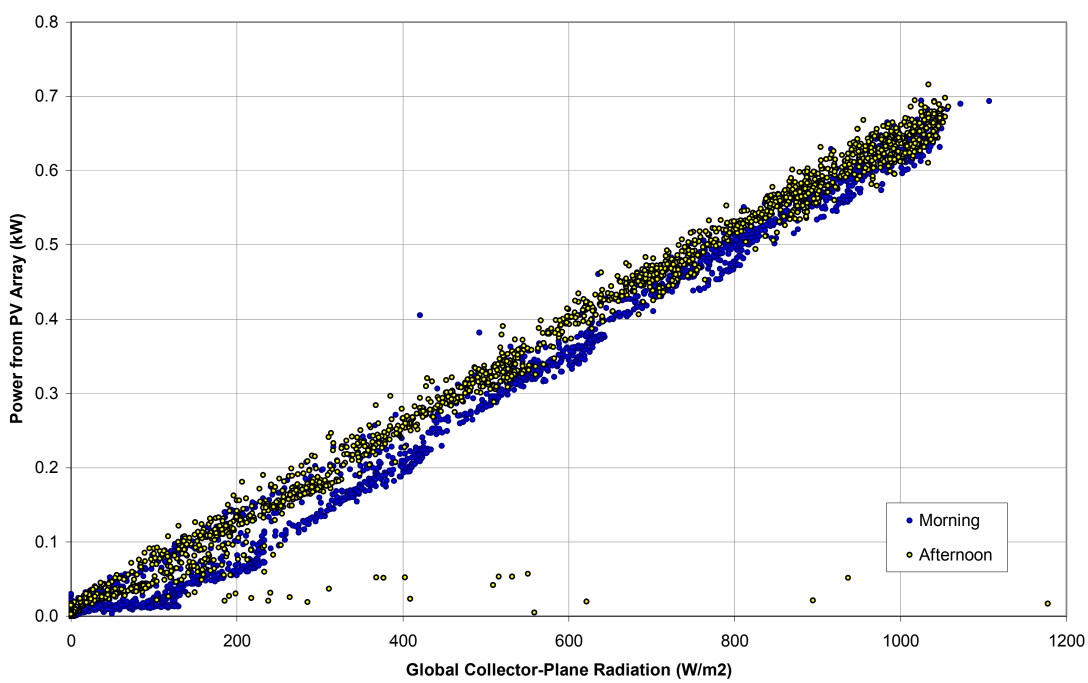


The next page contains scatter plots of the the wind generator's output versus wind speed, and the PV system's output versus incident solar radiation. The following pages contain "load profiles" – average monthly profiles of various measured and calculated quantities relevant to the performance of the hybrid system.

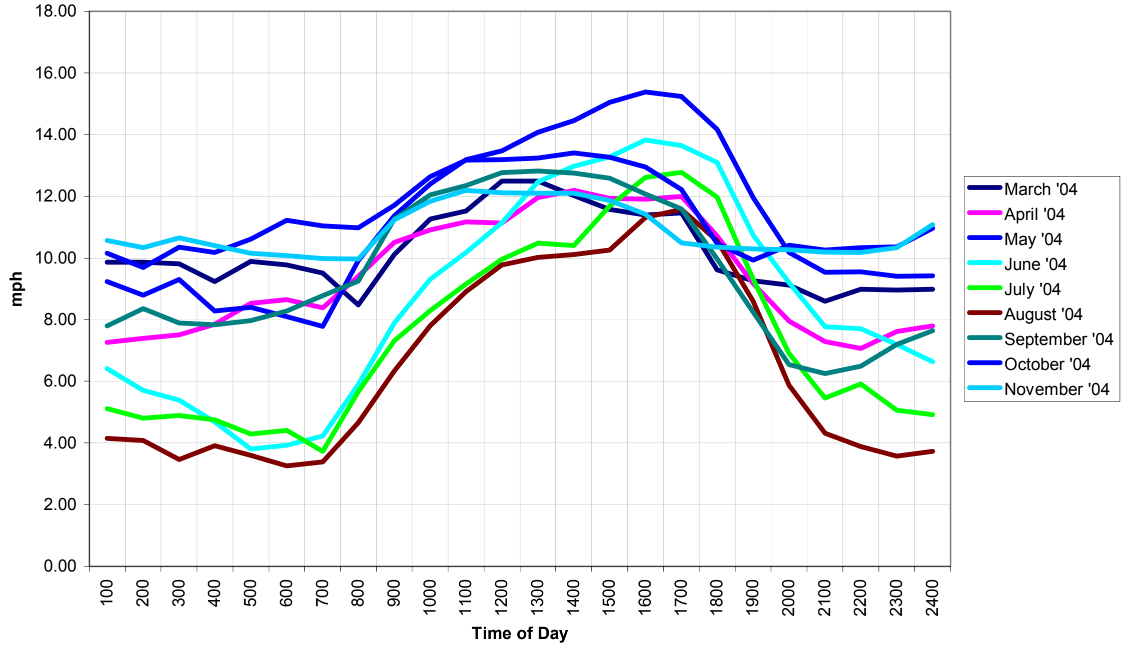
Power Generated by Wind Turbine



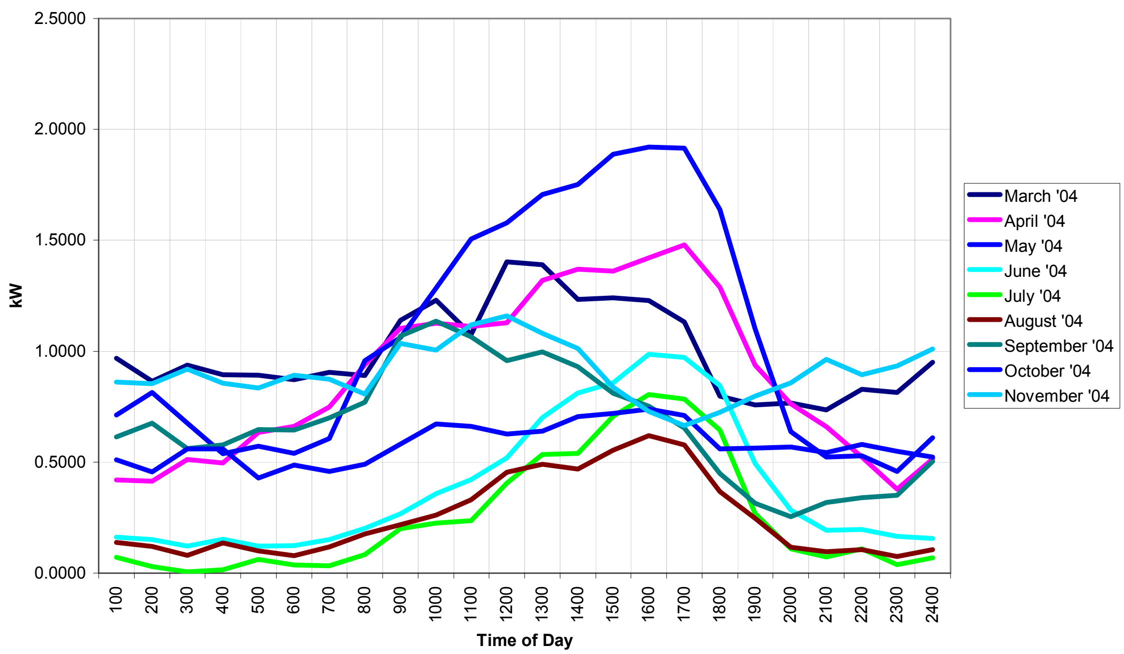
PV Energy Production vs Global Collector-Plane Radiation
Array Azimuth = 45 deg West of South

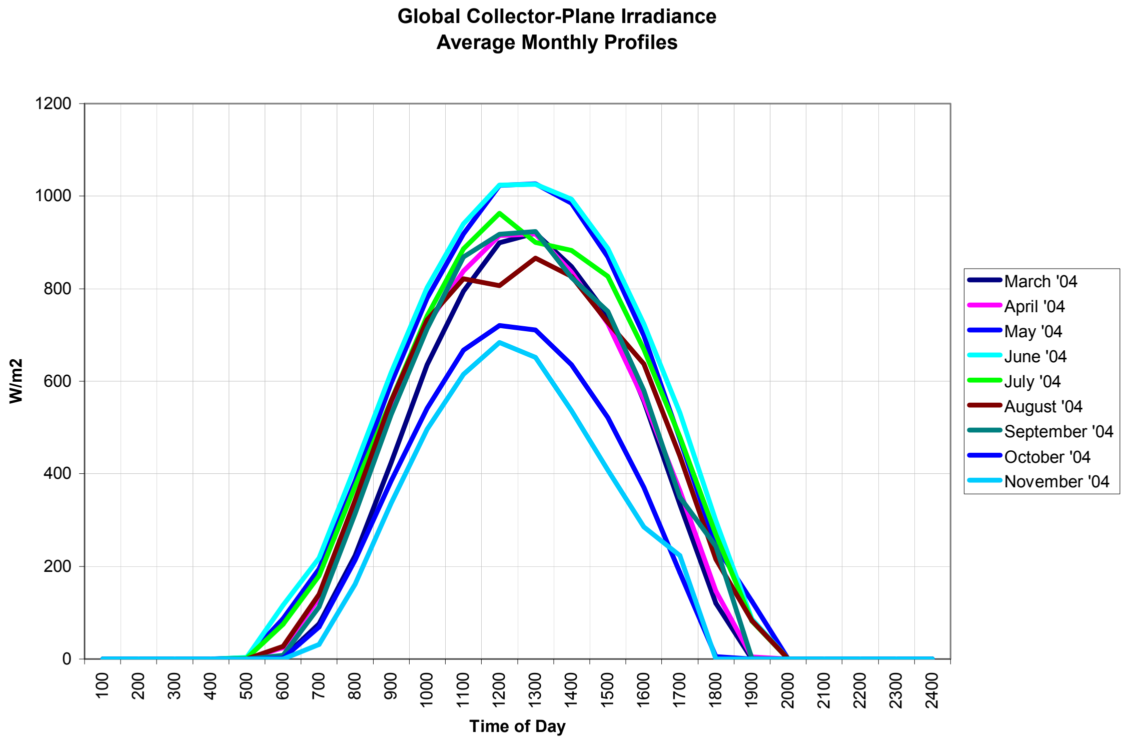


Wind Speed
Average Monthly Profiles

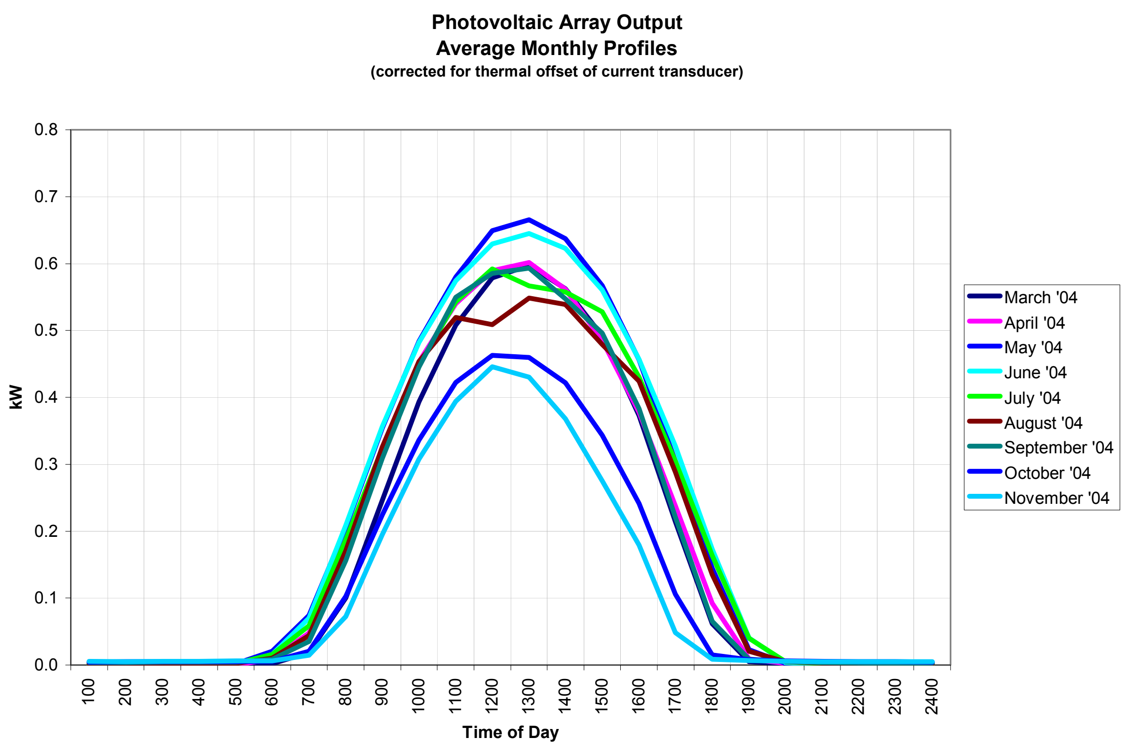


Wind Generator Output
Average Monthly Profiles

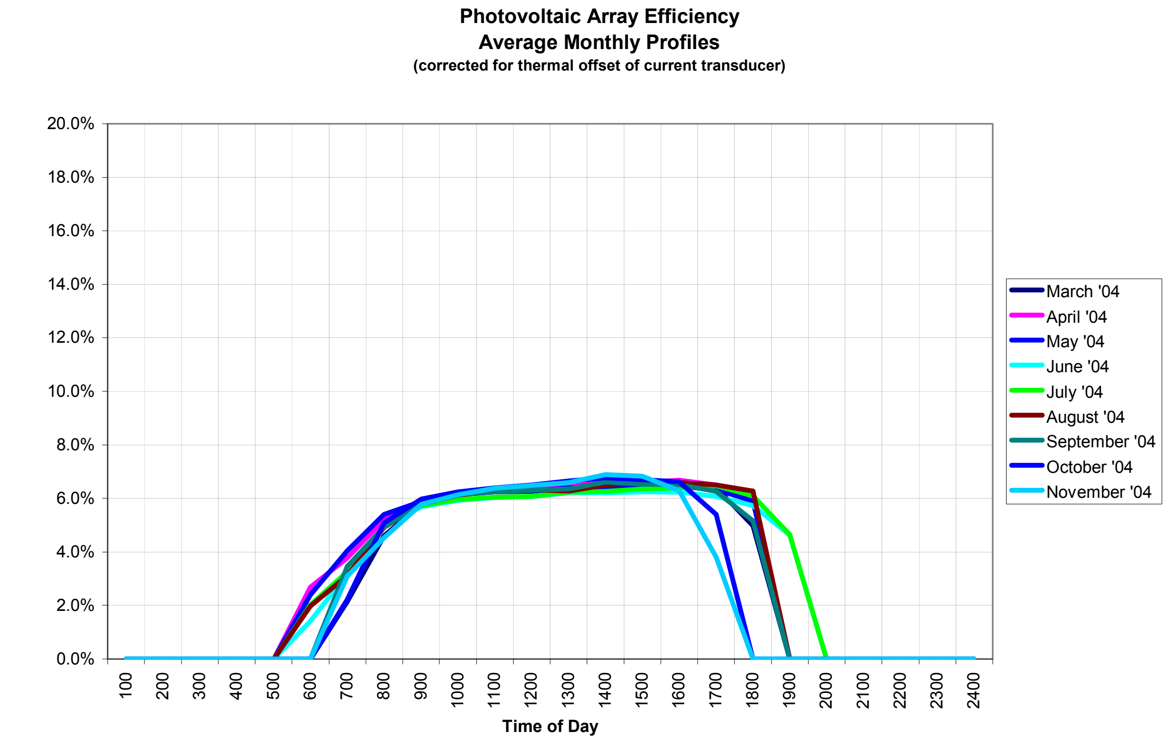


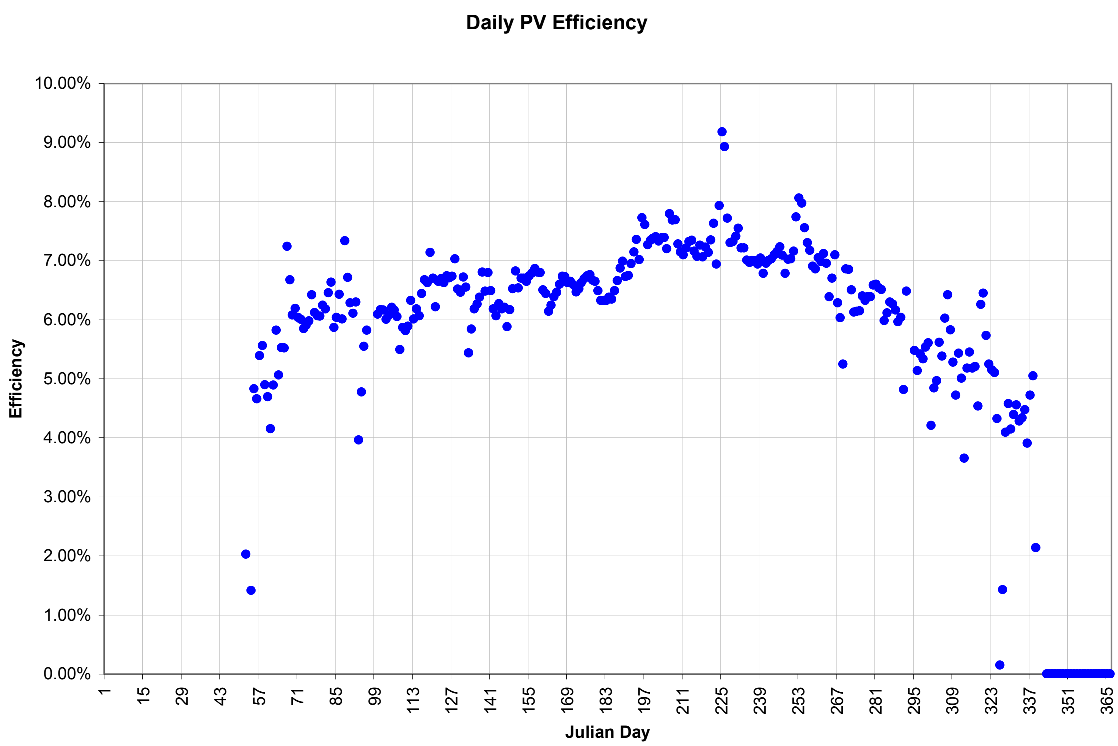


Global Collector-Plane Irradiance
Average Monthly Profiles
W/m2
Time of Day
0
200
400
600
800
1000
1200
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
March '04
April '04
May '04
June '04
July '04
August '04
September '04
October '04
November '04

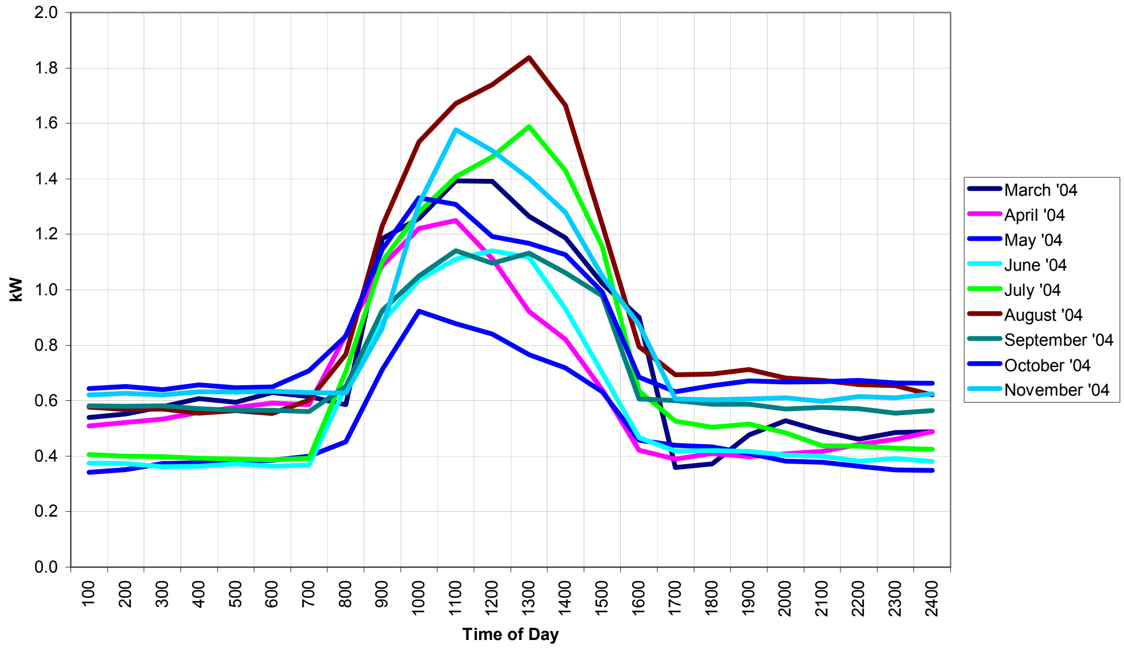


Photovoltaic Array Output
Average Monthly Profiles
(corrected for thermal offset of current transducer)
kW
Time of Day
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
March '04
April '04
May '04
June '04
July '04
August '04
September '04
October '04
November '04

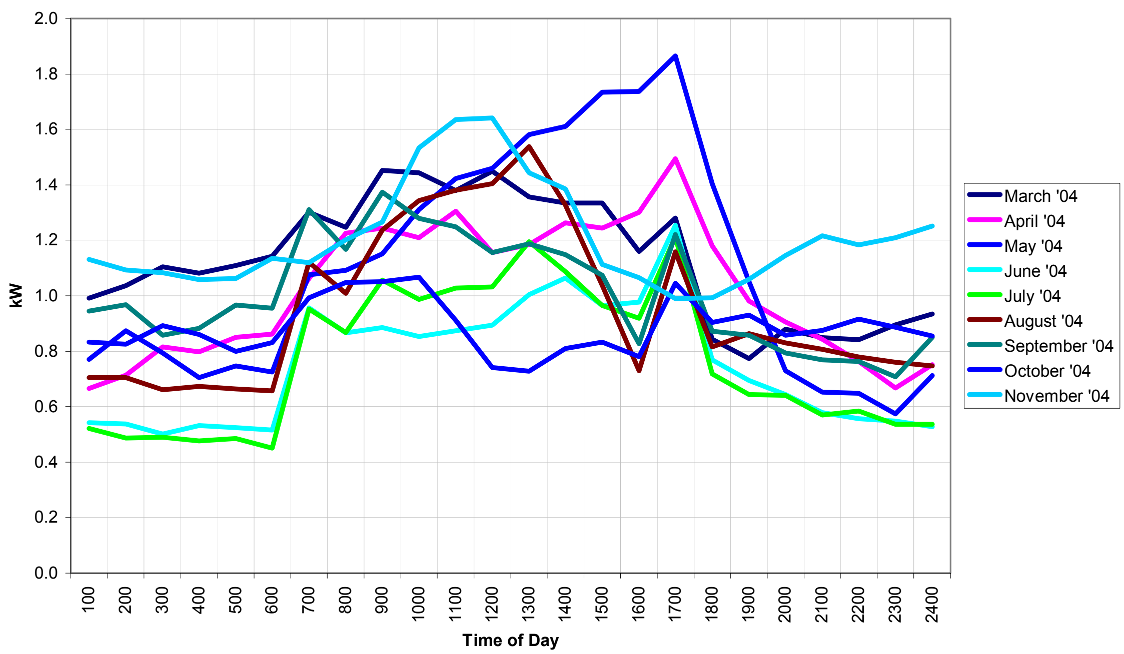

Photovoltaic Array Efficiency
Average Monthly Profiles
(corrected for thermal offset of current transducer)
20.0%
18.0%
16.0%
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
Time of Day
March '04
April '04
May '04
June '04
July '04
August '04
September '04
October '04
November '04


Daily PV Efficiency
10.00%
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
Efficiency
1
15
29
43
57
71
85
99
113
127
141
155
169
183
197
211
225
239
253
267
281
295
309
323
337
351
365
Julian Day

Total Energy to Critical Loads
Average Monthly Profiles



Renewable Energy to Non-Critical Loads
Average Monthly Profiles



Appendix G – NREL Report - Analysis of the Use of Wind Energy to Supplement the Power Needs at McMurdo Station and Amundsen

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Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory
Innovation for Our Energy Future

Analysis of the Use of Wind Energy to Supplement the Power Needs at McMurdo Station and Amundsen-Scott South Pole Station, Antarctica

I. Baring-Gould, R. Robichaud
National Renewable Energy Laboratory

Kevin McLain
Accurate Engineering

Technical Report
NREL/TP-500-37504
May 2005

NREL is operated by Midwest Research Institute   Battelle   Contract No. DE-AC36-99-GO10337

Analysis of the Use of Wind Energy to Supplement the Power Needs at McMurdo Station and Amundsen-Scott South Pole Station, Antarctica

Technical Report
NREL/TP-500-37504
May 2005

I. Baring-Gould, R. Robichaud
National Renewable Energy Laboratory

Kevin McLain
Accurate Engineering

Prepared under Task No. WER5.7202

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Executive Summary

This report summarizes an analysis of the inclusion of wind-driven power generation technology into the existing diesel power plants at two U.S. Antarctic research stations, McMurdo and Amundsen-Scott South Pole Station. Staff at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) conducted the analysis. Raytheon Polar Services, which currently holds the private sector support contract for the two research stations, was a major contributor to this report. Wind energy potential was not analyzed for Palmer Station or the various U.S. Antarctic field camps.

To conduct the analysis, available data were obtained on the wind resources, power plant conditions, load, and component cost. Whenever possible, we validated the information. We then used NREL's Hybrid2 power system modeling software to analyze the potential and cost of using wind turbine generators at the two aforementioned facilities. Unfortunately, the power systems and energy allocations at McMurdo and South Pole Station are being redeveloped, so it is not possible to validate future fuel use. Additionally, a new primary community/science facility at South Pole Station is under construction; thus only estimates of its expected power consumption are available. This report is an initial assessment of the potential use of wind energy and should be followed by further, more detailed analysis if this option is to be considered further.

McMurdo Station

We began wind speed measurement programs in late January 2003 at Twin Craters (NASA Dome Area), Crater Hill, and the Snow Dump, potential locations in close proximity to McMurdo Station. We experienced numerous anemometer failures (mainly broken cups) because of the harsh environment, but analysis of more than 6 months of reliable data from the three sites indicated that Twin Craters (near the explosives yard) has the most favorable wind speeds and persistence for wind-generating equipment. This area also has suitable road access for wind farm construction and maintenance. Because of the relatively small area available for towers at Twin Craters and the limited lift capacity of the existing crane a small number of different medium sized wind turbines were considered in the analysis.

Results indicated that capturing wind energy at McMurdo could reduce the total cost of generating power by between half a cent and 2 cents for each kilowatt-hour (kWh) produced by the power plant and reduce total fuel consumption by between 158,000 and 317,000 gallons/year (600,000 to 1,200,000 liters/year). Total net present savings for the use of wind, including all costs associated with the wind system installation, would be between $1 million and $4 million over a 20-year project life. The cost of the project was modeled to be between $2 million and $3 million.

Amundsen-Scott South Pole Station

The analysis for South Pole Station was conducted differently because of the limited availability of wind turbines that are suited for the extreme cold at the South Pole. The only existing large-scale wind turbine that fulfils the temperature requirements is Northern Power Systems' NorthWind 100 model, and it will require some development and retrofit work to allow reliable, long-term operation at the South Pole.

The analysis consisted of determining the cost savings based on installing between one and 10 NorthWind 100-kW turbines at the South Pole. Based on wind speed data collected at the South Pole metrological station, it appears that significant cost savings can be achieved by using wind energy. Although the wind speeds measured at the site are considered low, the avoided cost of fuel is so high that the installation of nine 100-kW wind turbines would result in a net savings of almost $18 million over a 20-year project life. Annual fuel consumption would be reduced by almost 23%, or 116,500 gallons (440,783 liters). The cost of installing nine turbines at the South Pole is expected to be approximately $4.3 million. Further analysis could be conducted to consider a heavier reliance on wind technology but as an initial stage 10 turbines was considered appropriate.

Conclusion

This initial analysis indicates that a large potential savings could be realized by incorporating wind energy into the existing diesel plants at the South Pole Station. The economic impact of using wind power at McMurdo is not as extreme, but it is cost effective and would significantly reduce diesel fuel consumption. Given the amount of wind energy that could be included in the systems at McMurdo and South Pole Station, the current diesel plants will continue to operate, at least initially, as they currently are. Any savings will result from a reduction in fuel consumption and subsequent reduced fuel storage requirements.

Both of these analyses are based on data that are generally out of date or limited in nature; thus the results should be considered preliminary. However, even with the limitations of the data used in the analysis, the increasing electric demand (which leads to increased fuel storage and transportation needs) and the growing cost of diesel fuel will only make wind more financially attractive in any further analysis.

To advance the assessment of these opportunities, several steps should be taken at the McMurdo and South Pole stations. These include obtaining better load and power system data following a detailed energy audit of each station; more advanced wind measurement at McMurdo and initiating a wind site-specific measurement program at South Pole. Additionally, further analysis is required to quantify the impact of reducing the available 'waste' heat from the generators due to the reduction of diesel generator electrical output.

Based on the results of this analysis, there is clear potential to use wind energy to reduce the power generation costs, harmful air emissions, and fuel needs at both stations. The next step would be to conduct more detailed assessment of potential options, turbines, and systems specifications.

Abstract

This report describes the analysis and investigation of wind energy's potential to reduce the quantity of diesel fuel consumed to provide power and heat to the two U.S. Antarctica facilities at McMurdo and the Amundsen-Scott South Pole Station. Staff from the National Renewable Energy Laboratory prepared this report with significant support from Raytheon Polar Services.

The analysis examined wind and load data from both stations and provides an initial estimate of the options for retrofitting these systems. The report also describes the next steps in the development of this project.

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Introduction

The initial investigation of the use of large-scale renewable technologies to support the power needs of the two major U.S. Antarctic research stations, McMurdo and the South Pole, began in 1999 with a visit of staff from the National Renewable Energy Laboratory (NREL). During this visit, it was determined that one of the main applications of renewable power would be the retooling of the diesel power plants that supply electric and thermal energy to these facilities.

Three basic areas of improvement were identified:

1) Use of thermal energy from the diesel plant for heating and process needs
2) Application of energy-efficient technologies throughout the stations
3) Use of renewable energy technologies to reduce diesel-produced power.

Raytheon Polar Services has aggressively pursued improvements for areas 1 and 2, while NREL has considered the application of renewable power technologies.

Because of the current high cost of photovoltaic power and the seasonal availability of sunshine, wind energy was considered the most feasible option for renewable power generation, especially given the significant size of the stations' power needs. The use of solar thermal building technologies and photovoltaics for small remote loads are viable options to supply energy needs in Antarctica, but they are not addressed in this report.

During a follow-up visit to the Antarctic facilities in 2002, several wind-monitoring sites were identified at McMurdo, and other data were collected from McMurdo and South Pole. In early 2003, monitoring stations were installed at three potential wind-generating sites at McMurdo, which has allowed the true assessment of the retrofitting potential at this station. Such measurement stations have not been installed at the South Pole.

The resulting analysis described in this report examines wind and load data from both stations, shows a comparative analysis of various wind-diesel power system combinations, provides an initial estimate of available options for retrofitting these power systems, and produces an initial economic assessment of these options. The comparative and financial analysis was primarily conducted using the Hybrid2 software (Baring-Gould, Hybrid2), which was developed by the University of Massachusetts and NREL. This tool provides a method to analyze the performance of different wind diesel power system combinations and produces an initial economic assessment of these options.

This report summarizes the current conditions and describes the data used in the analysis and the results of the analysis for each station. At the end of each section is a list of data requirements needed for further analysis. A primer on wind-diesel power system technology is also provided in the appendix of this document.

Most of the information contained from this report was obtained by personal communication and experience of the authors, specifically with Peter Somers at Raytheon

Polar Services. Additional information was obtained from unpublished reports: John Rand's Considerations of Renewable Energy Resources for the South Pole and several field reports filed by Ed Cannon following survey trips to McMurdo and the South Pole Station. Cost information for different turbine technologies was also obtained as part of similar wind diesel system assessments being carried out for communities in Alaska.

McMurdo Station

Existing Conditions

McMurdo is located on a volcanic island about 20 miles from the mainland of Antarctica and 2400 miles due south from New Zealand. The town site (population 1000+) sits on a southwest-facing beach area at the foot of several large hills, including Arrival Heights/Twin Craters and Crater Hill. The station consists of many buildings and is more similar to a small town than a field station. The buildings, of many different construction styles and ages, are maintained to provide the primary hub of research facilities, housing, and services to all U.S. (and some international) activities in Antarctica. The site has a seasonally active harbor where supply and fuel vessels can dock and unload cargo after a channel is created by an icebreaker. Power requirements for the stations infrastructure, laboratories, and science experiments are quite large —16,000 megawatts (MW)/year—, and reliable, high-quality power is essential.

Potential Wind Turbine Sites

Data were initially collected in mid-January 2003 at three sites in the area of the McMurdo facility: Snow Dump, situated in "The Gap" near Scott Base; Twin Craters, a location immediately above and a little to the north of the McMurdo station; and Crater Hill, which is to the northeast of McMurdo station. The Snow Dump and Twin Craters sites are accessible by road, but Crater Hill currently does not have road access. Twenty-meter towers were installed at each site and outfitted with NRG Systems data-logging equipment to record wind speed and direction information. Wind data collected at McMurdo's main facilities and at a nearby NASA radar site were not considered reliable or appropriate for wind power assessment.

High winds and extreme temperatures have caused problems with the reliability of the anemometers. Therefore, a clear and long-term description of the wind speeds at the sites is not available.

Based on these data, for the periods of concurrent measurements, the Twin Craters site has a better wind resource than either Crater Hill or the Snow Dump site. Because uninterrupted data are not available for the whole year, it is unclear if this is always the case, especially during the months of high and low wind velocity: May and January, respectively. Beyond the incomplete wind assessment, however, Twin Craters is accessible by road and is located only about 0.5 miles from a 4160-V transmission line, making it a strong preliminary first choice for wind tower placement. Further analysis considering other siting issues, such as the impact on scientific research, historic preservation, and environmental impact, will also have to be addressed.

Energy Consumption

Two types of loads are described for the McMurdo station: electric and thermal. The electric loads provide all electrical needs and a good amount of electrically based heating. Electrical-load data from December 2001 through March 2003 were obtained from the plant. For the full year of 2002, the electrical consumption for McMurdo was 15,823 megawatt-hours (MWh).

Presently, heat is removed from the diesel generator's engine jacket coolant loop and is used to heat specified buildings, with an expected JP-5 fuel oil savings of 470,000 gallons/year (1,779,000 liters/year). Furthermore, with an upcoming redesign of the diesel power plant, additional waste heat will be available from the exhaust stacks to preheat ocean water for the reverse osmosis desalination equipment and for heating other appropriate buildings at McMurdo. However, this thermal energy usage is not tabulated and thus was hard to determine as part of the analysis.

Diesel Power Plant

The diesel power plant is currently being redeveloped to replace outdated diesel generating and control systems and technology. The new diesel plant will be made up of six Caterpillar diesel generator sets: four model 3516B for base load and two model 3512B to satisfy peaking demands.

The soon-to-be-renovated power plant consumes approximately 1,300,000 gallons/year (4,921,000 liters/year) with an average efficiency of approximately 11.5 kWh/gallons (3.04 kWh/liter) in 1999. Cost of delivered fuel used in the analysis was $1.30/gallon (0.343/liter), which represents the cost in 1999. Costs in late 2003 were $1.48/gallon (0.390/liters) and increased to $1.71/gallon for 2005. This results in a 1999 cost of 11.3 cents/kWh for fuel alone. The cost of diesel generator operation (maintenance, lubrication oil, equipment overhaul including labor) is approximately $15/hour, which in most cases would add an additional 2 to 3 cents per kWh produced. This savings, however, is only achieved if the diesel engine can be shut off completely and thus does not impact the economics in this analysis.

The diesels also support thermal loops running from the jacket and engine exhaust that is used for space or water heating. Of the total caloric energy of the diesel fuel, energy output from the diesel generators is expected to be divided as follows:

- 31% to useful electric power
- 30% is consumed by the jacket (part of which is used to heat buildings through a glycol loop)
- 39% is lost in the exhaust, although plans are underway to recapture some of this energy as well.

Because the engines' residual heat is used extensively, any system modeling that reduces the heat generation from the diesel engines must include the economic impact of this loss, either by generating more energy through renewable technology or through the burning of more heating oil. At the time of this analysis, the impact of this loss of heating has not been taken into account, although its impact will not be too great.

Shipping Information

In 1999, the estimated cost of shipping equipment to McMurdo was \$1.4/lb (\$3.09/kg) by air and \$0.17/lb (\$0.37kg) by ship.

Analysis of McMurdo Wind Power Options

This section describes the data used in the analysis for McMurdo Station, as well as the assumptions regarding installation and the operation of the diesel power station. This initial analysis primarily examines the amount of wind energy that could easily be absorbed into the diesel grid at McMurdo station. The report also describes wind energy equipment options and further information that is needed to allow refinement of the analysis.

Three types of data are important for the analysis of wind co-powering options. The first relates to the technology that can be used to provide power at each of the sites, the second is the energy consumption at each site, and the third is the available wind resource. These data must then be analyzed based on an understanding of the current plant structure and other limitations that each site may present.

Turbines Used in the Analysis

Turbines analyzed for use at McMurdo were selected primarily to reflect different size categories or classifications, not to represent specific turbines or manufacturers. A sample of possible turbines is provided in Table 1, although other options are certainly available. Although there are differences between specific turbines, at this level, issues of basic cost, generation capacity, weight, and size are most critical. Once a turbine class is selected, further analysis will be required to determine which turbine manufacturer and model may be the most appropriate.

A number of horizontal-axis wind turbines may be appropriate for use at McMurdo station. Turbines most used in arctic environments include units from Bonus Wind Systems and ENERCON. Three ENERCON wind turbines were used with success to re-power Australia's Mawson Research Station on the Antarctic coast south of Australia. U.S. patent issues may eliminate the possibility of using ENERCON wind turbines in any U.S. project, but more research is needed on this issue.

Table 1: Various Wind Turbines Considered in Analysis

Company	Country	Turbine	Power (kW)	Temperature Rating
Entegrity Wind Systems Inc.	Canada/USA	EW15	50	-40
Lagerwey Windturbines	Netherlands	18/80	80	-35
Northern Power Systems	USA	NW100/19	100	-50
Vergnet WE Development	France	GEV 26/220	220	Not Available
Fuhrlander Wind Turbines	Germany	FL 250	250	Not Available
ENERCON GmbH	Germany	E-30	300	-35

At this point in the analysis, two wind turbines were considered for McMurdo: the Northern Power Northwind 100/19 (the standard form of the 100-kW Northwind turbine) and the Furlander FL 250, a standard 250-kW wind turbine. The Northern Power wind turbine represents a smaller, more rugged "specialty" turbine, while the Furlander represents a larger mainstream turbine. These two turbines were chosen to represent different classes of turbine choices and NREL makes no recommendation on either turbine choice. If the project were to move forward, different wind turbine companies would be contacted to provide specific information regarding the technical specification and availability of turbines for McMurdo.

The McMurdo analysis examined the installation of a number of different wind turbines to be directly connected into the diesel grid of the station. As described previously, the site at Twin Craters was selected as the most likely location for the installation of the turbines.

Wind Data

The wind data set that was used for the analysis was created using data collected from the three wind measurement locations. Historical wind speed data from McMurdo were used to evaluate long-term trends compared to the data recorded at the site. It should be noted that the historical wind speed data are from a location down in the community and were not used to predict wind speed, just to verify seasonal variation. A summary of the data collected through April 2004 is provided in Table 2, and data for Twin Craters are summarized in Figure 1. More data have been collected at Twin Craters since April but were not used in this analysis.

To the extent possible, all recorded data from the measurement sites were used in the creation of the wind data file used in the analysis. The wind data for Twin Craters is not continuous and does not cover an entire year, indicating that more data collection is needed. However, for the purposes of an initial scoping and recommendation report, stitching together various wind data reports from nearby sites has provided a rough (but reasonable) estimate of wind profiles and characteristics.

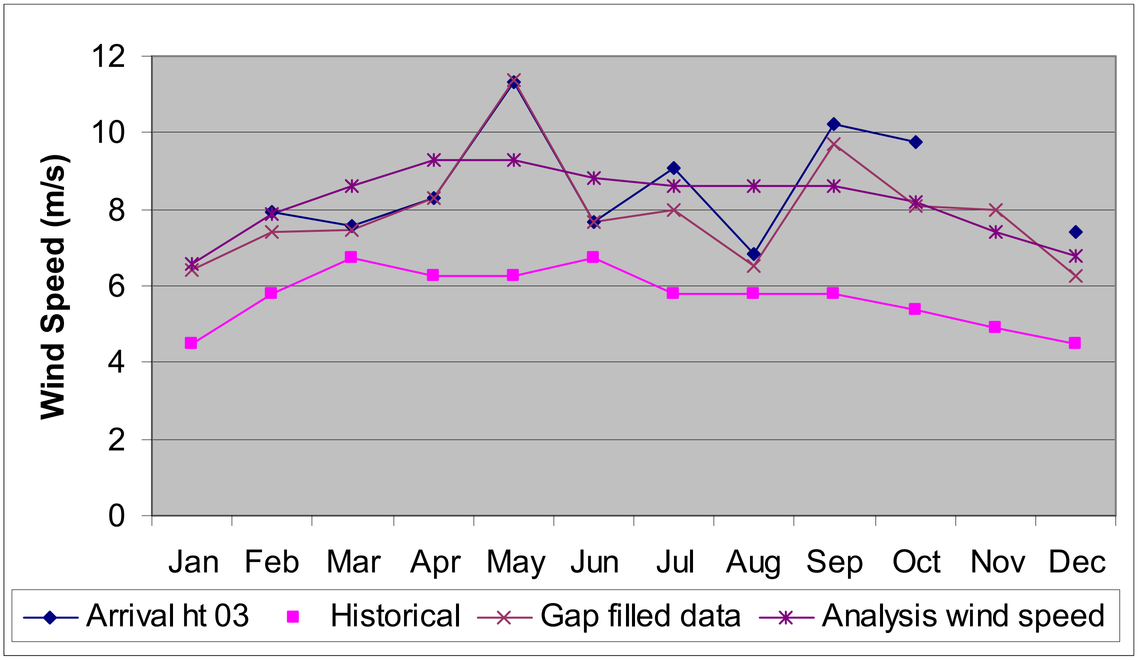

Figure 1. Wind speed data from Twin Craters (2003) and historical wind speed data from McMurdo Station

Table 2: Summary of Collected 20-m Wind Speed Data from Three McMurdo Station Sites

Crater Hill				Twin Craters				Snow Dump			
Date	*Average mph*	*Gust mph*	*Direction Polar*	*Date*	*Average mph*	*Gust mph*	*Direction Polar*	*Date*	*Average mph*	*Gust mph*	*Direction Polar*
1/25/03		Sensor Installed		1/24/03		Sensor Installed		1/29/03		Sensor Installed	
to 2/20	14.9	56	146	to 2/18	16.7	108	200	to 2/3		Bad Data	
3/19/03	16	71	174	3/20/03	17.04	71	204	2/18/03	11.1	40	219
4/19/03	14.9	90	158	4/19/03	15.9	84	180	3/19/03	11.2	55	225
5/20/03	23.88	98	146	5/23/03		Missing		4/19/03	11.3	63	221
6/19/03	20.05	99	174	6/20/03		Bad Data		5/20/03	15.85	72	226
7/5/03	19.95	69	148	7/25/03		Bad Data		6/19/03	13.28	85	229
7/24/03		Bad Data		7/26/03		Missing		7/12/03	12.5	50	228
8/22/03		Bad Data		8/22/03	17.44	108	200			Removed	
10/1/03		Bad Data		9/23/03	17.81	95	159				
		Removed		10/13/03	23.14	85	187				
				12/9/03		Bad Data					
				12/23/03		Missing					
				1/8/2004	15.74	55	159				
				2/5/2004	14.78	44	72				
				3/4/2004	15.35	62	56				
				4/6/2004	16.69	56	72				
	Average	**18.28**	**mph**		**Average**	**17.65**	**mph**		**Average**	**12.538**	**mph**
Maximum gust		**99**	**mph**	**Maximum gust**		**108**	**mph**	**Maximum gust**		**85**	**mph**

It should be noted that the Crater Hill site experienced extremely high winds during May 2004, which is also reflected in data from the Snow Dump site. It appears that this was a singular event, so the wind speed for this month was scaled down to more accurately reflect the historical data. All data collection was completed at a 10-minute interval and averaged to 1 hour to use in the first level of system analysis. All measurements were conducted at 20 meters.

To conduct the analysis, available data from Twin Craters were used, which accounted for data from February 24 to April 19, September 22 to October 13, and December 23 to the end of the year. From April 19 to July 5, data from Crater Hill were used in the place of Twin Craters, except for a short period of absence of data in July. A scatter plot of concurrent wind speeds from February 25 to April 19 shows good correlation between the two data sets with Twin Craters from most directions. From July 5 to 13, data from Snow Dump were used with an appropriate scale factor, again based on comparisons between Twin Craters and Snow Dump. For the rest of the year, from December 1 to February 24 and from October 13 to December 23, no detailed time-series data exist. To assess the resources during these times, long-term historical data from McMurdo were used. A time series of the wind data used in the analysis is provided in Figure 2.

At the time of the analysis, approximately 8 months of actual site-related data were available, which is not sufficient to finalize the analysis for this system. It is critical that more data be obtained for the site to clarify the fall and winter wind profile and that the data be taken at a height of between 20 and 30 meters to more closely match the wind turbine's hub height.

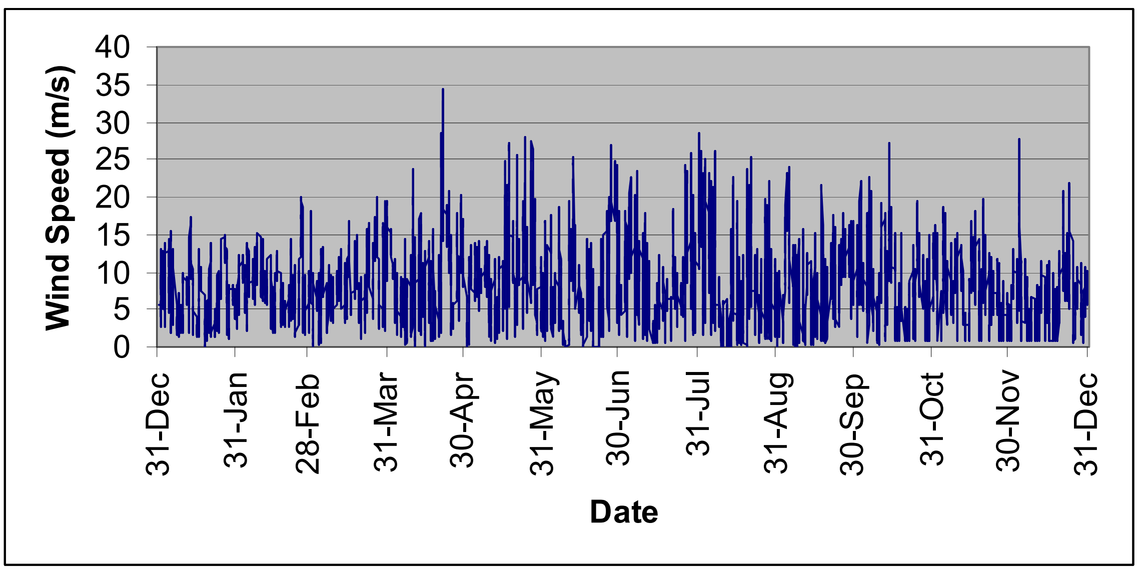

Figure 2: Wind speed data used in the analysis for McMurdo Station

The maximum recorded wind speed at the sites for the year was more than 107 mph (48 m/s), which is near the maximum range for a number of the turbines under consideration. Additionally, in March 2004, sustained wind speeds of 140 mph (62.8 m/s), with gusts up to 188 mph (84 m/s), were recorded at the NASA radar site located about 0.25 miles (0.4 km) from the Twin Craters. This will be a critical issue in determining which turbine may be the most appropriate for the application.

Load Data

Raytheon Polar Services provided load data in the form of general plant output power every 10 minutes between December 2001 and March 2003. The monthly averages for these data are provided in Figure 3. Because of problems with the time step of the data files, we decided to use the full year of data from 2002. Year-to-year load growth varies between less than 1% to slightly more than 4%, so although this will be considered in future analysis, we expect that the impact will be small.

Figure 4 depicts a plot of the time-series data used for the analysis.

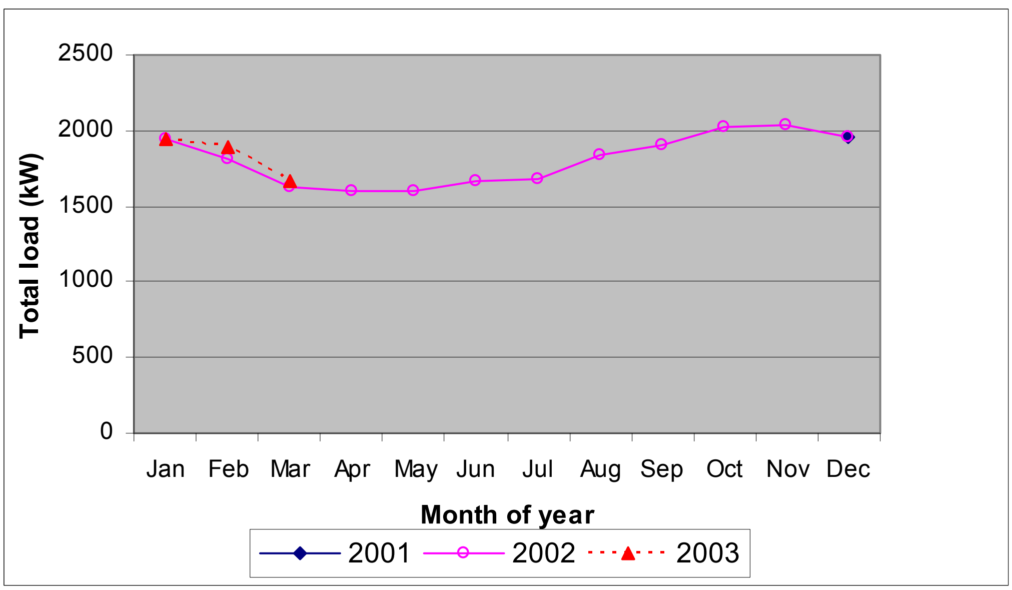

Figure 3: Historical load data for McMurdo Station

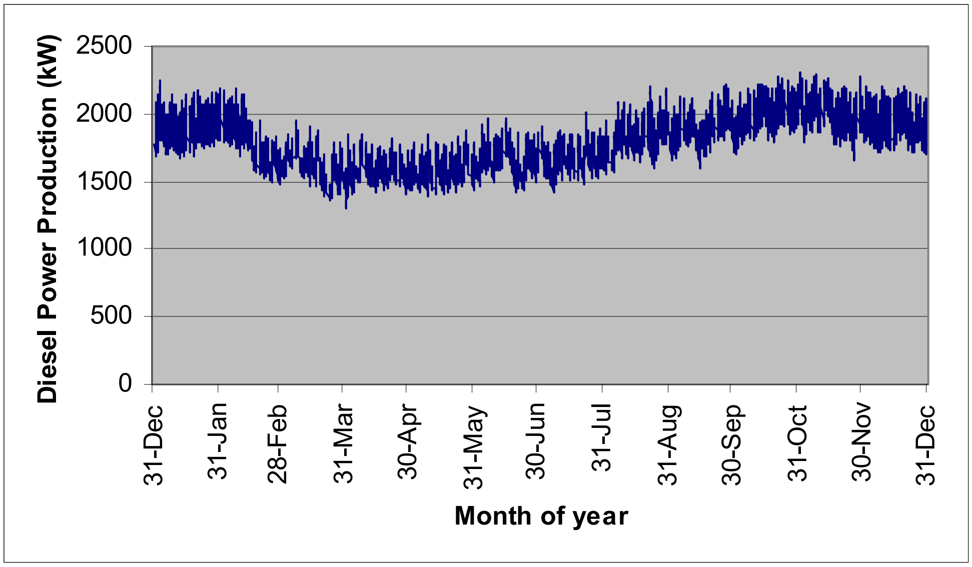

Figure 4: Load data used in the McMurdo Station analysis

Diesel Plant

The diesel plant was modeled using six Caterpillar 1418 kVA (1135-kW) prime power diesel gensets driven by 3512B diesel engines. This model was completed because of an inability to access data on gensets based on the Caterpillar 3516B diesel. Additionally, the specific size and ranking of the diesels to be used in the new McMurdo power house were not known. Once the size of the diesels is known, data can be obtained on the specific diesel engines to be used. Typically three diesels are operational to allow reserve capacity.

One additional simulation was completed, including a smaller 600-kW (750-kVA) Caterpillar generator based on a 3508B diesel engine to determine whether allowing more refined sizing would impact system costs.

Retrofitting Constraints

Several constraints need to be defined before further analysis can be conducted. The site at Twin Craters is constrained in size, which will limit the number of wind turbines that could be installed at this location. The ridge, which fortunately lies perpendicular to the pervading wind direction (Figure 5), measures about 700 ft (230 m) long and 150 ft (50 m) wide. The crane at McMurdo that could be used to install the turbine has a maximum lift height of 135 feet (44.3 m) and has a maximum lift capability of 10,500 lb (4762 kg). The capacity of the crane will limit the size of the wind turbine that could be installed.

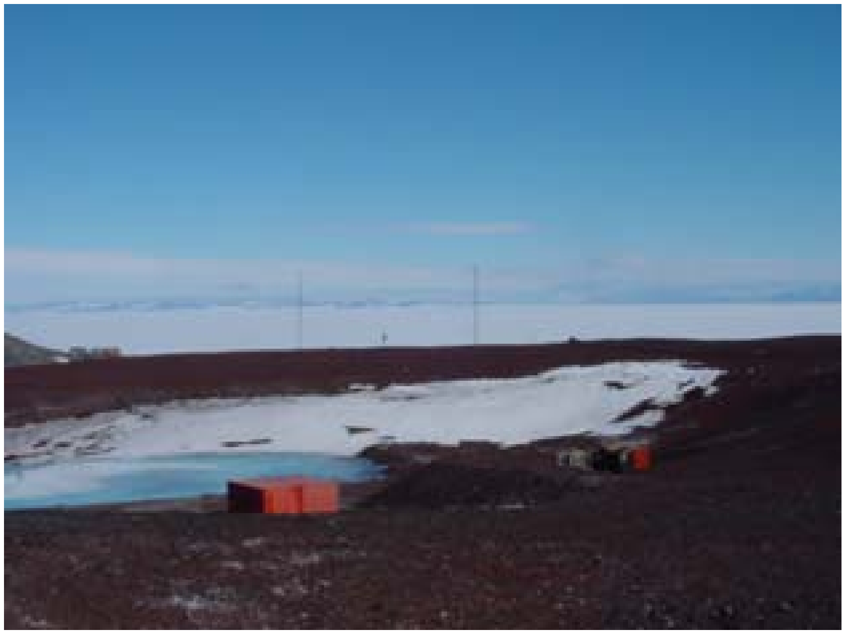

Figure 5: Twin Craters overlooking the McMurdo Station

Results of McMurdo Station Options Analysis

McMurdo has a large energy demand and is constrained by space limitations at Twin Craters. This means that only a limited number of wind turbines could be installed at this site, limiting the potential installed wind capacity.

Based on the assumed diesel power station configuration, manufacturer's fuel consumption information, and the measured load, a fuel consumption of 4,878,225 liters was estimated using the Hybrid2 software. This can be compared to the 4,921,000 liters that was consumed by the old diesel plant in 1999. The new diesel plant will have higher efficiency, but the load has also increased, and the close proximity of these numbers adds some credence to the analysis methodology. Based on this consumption, the cost of energy based only on diesel fuel is $0.1589/kWh.

For this first level of analysis, two turbines were considered: the Northwind 100/19 (the standard form of the 100-kW Northwind turbine) and the Furlander FL 250 (a standard 250-kW wind turbine). Both of the turbines used in the analysis meet the requirements of the crane at McMurdo station.

The minimum spacing of a wind turbine is two rotor diameters, but this is highly dependent on a wind rose for the site, which has not been completed because of the lack of reliable wind direction data. Based on the dimensions of the Twin Crater site, which is 700 ft (230 m) long, it would be possible to place as many as five ~250-kW wind turbines, although four would be more likely. If smaller turbines were used, a total installed capacity would likely be smaller, although more turbines would be used. The analysis examined using seven Northwind turbines with a total installed capacity of 700 kW and then two installations of the Furlander FL 250, five turbines with a nominal installed capacity of 1250 kW and four turbines with nominal installed capacity of 1000 kW. It should be noted that the actual maximum performance of the Furlander FL 250 is actually 300 kW at a wind speed of 21 m/s (~ 47 mph).

Based on simulations using the Hybrid2 software, the amount of fuel consumed and the overall cost of energy decreases with the inclusion of wind energy. Table 3 shows the results of several different power system configurations using different wind turbines. The potential fuel savings depends on the system selected, but ranges from 13% to 24.9%, with a maximum fuel savings of more than 320,700 gallons/year (1,214,000 liters/year). Based on the 2002 electrical energy use, which averages between 1.5 and 2.0 MW, up to 25% of the station's electrical energy would be generated by wind.

Table 4 provides on overview of expected project economics based on the analysis of the same system configurations introduced in Table 3. In this table, the capital cost of several different options is provided, along with the systems 20-year net present cost (NPC), or the total cost of the power system for the next 20 years. A reduced NPC indicates that this option is less expensive on a life-cycle basis. Cost of energy (COE) is also provided, though care should be used when looking at these numbers because not all power system costs, such as operators and other infrastructure expenses, have been included in the analysis as the use of wind power is not likely to change these costs. A number that provides more information is the figure representing the difference in COE produced. This number shows, based on the items that were included in this analysis (primarily diesel fuel, system operation, maintenance, and capital costs), the expected reduction in costs using different system configurations.

Table 3: Performance Impact of Using Wind Energy at McMurdo Station

Input					Performance Results		
Type of Turbine	*# of Turbines*	*Installed Nominal Capacity (kW)*	*Engine Size (kW)*		*Fuel used l/yr*	*Fuel Savings %*	*Fuel Savings l/yr*
All diesel system					4878225	n/a	n/a
NW 100	7	700	6x1135 kW		4243632	13	634593
FL 250	4	1000	6x1135 kW		3876228	20.5	1001997
FL 250	4	1000	Small Dsl		3696438	24.2	1181787
FL 250	5	1250	6x1135 kW		3664099	24.9	1214126

Table 4: Economic Impact of Using Wind Energy at McMurdo Station

Input			Economic Results			
Type of turbine	*Turbine #*	*Engine Size (kW)*	*COE $/kWh*	*Difference $/kWh prod*	*20-Year NPC $*	*Capital Cost, $*
All diesel system			$ 0.1589	$ -	$ 30,809,210	$ -
NW 100	7	6x1135 kW	$ 0.1542	$ 0.0047	$ 29,889,266	$2,302,886
FL 250	4	6x1135 kW	$ 0.1423	$ 0.0166	$ 27,589,012	$2,140,400
FL 250	4	Small Dsl	$ 0.1377	$ 0.0212	$ 26,693,168	$2,140,400
FL 250	5	6x1135 kW	$ 0.1383	$ 0.0206	$ 26,824,676	$2,675,500

Given these cases, the use of wind energy at McMurdo could reduce the total cost of generating power by between 1/2 a cent to 2 cents per kWh. Over a 20-year expected life of the equipment, the total savings, including all capital costs, ranges between $1 million and $4 million, although most wind turbines have a design life of 30 years.

The analysis also demonstrated that the inclusion of a smaller peaking diesel also makes economic sense, resulting in almost a 4% reduction in fuel consumption. The new diesel plant at McMurdo will include two smaller peaking diesels, but some analysis might be warranted to determine their optimal size, even if wind energy is not to be included in the power system redesign.

As stated previously, this analysis does not include the impact of the reduced waste heat from the generators based on the reduction in fuel consumption. Because the diesel engines will continue to be used even while the turbines are operating, thermal energy from these units will still be available to provide existing heating loads. However, a reduction in the amount of fuel consumption will have an impact on the amount of heat available for other loads. A technical and economic assessment will have to be conducted to determine the impact of the loss of waste heat from the diesel plant.

Costs associated with reducing the need for fuel storage at McMurdo has not been included in this analysis but will add additional savings.

Further Data Needed to Refine the McMurdo Analysis

The following data should be obtained to refine the analysis conducted as the basis of this report.

Load

- Better understanding of the thermal loading systems
- Information on the Reverse Osmoses (RO) water desalination unit, power rating, fresh water storage capacity, and usage
- Temperature data for the site (to determine thermal energy requirements)
- Temperature setting for the buildings (to determine temperature coefficient)
- Updated station electrical energy requirements.
- Conduct a detailed energy audit of current and planned buildings

Diesel Plant

- Clarification of the current diesel configuration, unit specification, and size
- Fuel-use curves of the diesel engines on site
- Updated information on fuel price, usage, and storage availability
- Costs of expected fuel storage expansion.

Wind Data

- Additional wind speed data from Twin Craters at a height of 20m to 30m
- Historical wind data from McMurdo Station
- Wind rose for Twin Craters anemometry.

Constraints

- Further analysis of Twin Craters site, including soil type, road rating, power line extension, etc.
- Analysis of potential impact of wind turbines on any ongoing or planned scientific experiments

Amundsen-Scott South Pole Station

Existing Conditions

At a 9,400-ft physical elevation (11,000-ft physiological elevation) and with temperatures ranging from -115°F to +6°F (-82°C to -14°C), South Pole Station sits on a slowly moving Polar Plateau ice field at the earth's geophysical south pole spin axis. The station supports year-round scientific activity, and the original dome facility is currently being replaced by a new above-snow facility that will greatly expand the services and living conditions at the Pole. As part of this major redevelopment activity, the power plant was completely redesigned, and the primary generator waste heat (engine jacket and exhaust) is fully captured and distributed to various buildings.

One limiting factor at South Pole is that all supplies, equipment, and personnel must be flown into the site during a short, 4-month summer season. The large amount of diesel fuel needed to power and heat the station continues to constrain the cargo capacity and places extreme logistics and performance pressure on support personnel, scientific research, and station services. As the electrical needs at the site grow, this problem continues to worsen. Additionally, the cost of transporting fuel by air raises the price of the fuel to well over $10/gallon. The utilization of wind power to replace some amount of diesel consumption is one option to reduce the required import costs. Other options, such as developing a land-based supply train, are also being investigated.

The energy requirements of the South Pole station are difficult to obtain, primarily because the station is in the process of receiving a major upgrade. In the 1999 to 2000 year, fuel consumption for power generation was 258,284 gallons (977,708 liters) per year, which makes up approximately 71% of the fuel consumption at the site. These numbers apply to the operation of the older diesel power plant, which was replaced in 2001 and 2002, and the older facilities. Yearly fuel usage for the new diesel power plant at the new facility is projected to be 341,000 gallons (1,290,821 liters). Based on current consumption, power generation requires the importation of 1,160 short tons (1,052 metric tons) of fuel to the station.

Research and installation of small-scale towers and wind turbines at the South Pole has provided valuable hands-on experience with some of the critical issues. Challenges to be overcome are many, including efficient transport of materials to the site; snow foundation design; improvements to cold-hardened equipment; operation, maintenance, and repair issues; and mitigation of possible electromagnetic interference. Each of these issues will have to be considered as part of any project-development or detailed analysis process.

Wind Speed Data

Almanac data state that the average wind speed for 2000 was 11.5 mph (5.14 m/s) with a maximum wind speed of 45 mph (20.1 m/s), whereas the average for 2001 was 12.4 mph (5.54 m/s) with a maximum wind speed of 44 mph (19.7 m/s). It is also reported that the wind speed is in excess of 5.0 m/s approximately 70% of the time, although this cannot be confirmed.

Energy Consumption

Load data are available for the existing South Pole station and averages 384 kilovolt amperes (kVA). Thermal energy from the generator's water and jacket heat will be used for space heating of the primary station buildings and to melt ice for water. Energy estimates for this new facility places usage at around 500 kW, ranging from 467 kW during the summer and 510 kW during the winter, although this has not been confirmed. Using John Rand's analysis, every extra MWh of supplanted diesel power will require the import of 48 gallons (181 liters) of fuel for heating.

Diesel Power Plant

The current power plant, installed in 2001 as part of the station retrofit, is made up of three Caterpillar 3512 diesels with 750-kW generators and one Caterpillar 3412, 250-kW generator. One of the larger generators operates continuously, alternating operation, while an additional large unit is on standby. The 250-kW diesel is used for peaking.

Local Information

The cost of shipping equipment to the South Pole from McMurdo is about $1.57/lb ($3.47/kg). This results in a total cost of shipping equipment from the United States by air and ship at $2.97/lb ($6.55/kg) and $1.74/lb ($3.83/kg), respectively. Delivered diesel fuel at the South Pole cost is projected to be between $12.00 ($3.17/l) and $15.70 ($3.78/liter) per gallon (John Rand report).

Analysis of South Pole Station Wind Power Options

This section describes the data used in the analysis for South Pole Station, as well as the assumptions regarding installation and the operation of the current diesel power stations. This initial analysis primarily examines the amount of wind energy that could easily be absorbed into the diesel grid at the South Pole Station. It also describes wind energy equipment options and further information needed to allow refinement of the analysis.

The analysis of the retrofit potential as a high-penetration power system of the South Pole Station was more expansive than the analysis of McMurdo. Given the energy consumption and space limitations at McMurdo, this station would not have been suitable for such a power system. It is assumed that the implementation of a high-penetration power system at the South Pole would be a slow process, which would likely start with the installation of a small number of wind turbines with the appropriate control equipment to gain operation experience before more turbines were installed. Assuming the wind turbine operation was satisfactory, it would be expected that the implementation of the complete system would take place over 3 to 5 years. This report discusses the initial stage of this activity only, leaving analysis of more extravagant options, such as a no-diesel wind and stored hydrogen power system, for another time.

Turbines Used in the Analysis

Currently, no utility-scale wind turbines are available that have a low enough temperature rating to enable operation at the extreme temperatures found at South Pole. The only turbine that comes close to fulfilling the temperature requirements is the NorthWind 100 by Northern Power Systems, although some cold-related development work is still needed on this product. One of the modifications for this turbine will likely include the use of an enlarged rotor (20-m diameter instead of the standard 19.1-m rotor) to improve power capture in the lower wind speed environment of the South Pole. The standard NorthWind 100 was used for this analysis although additional costs have been added to the base cost of the turbine to account for the additional modifications required for an Antarctic version. The costs do not include development expenses to lower the operating temperature of the turbine below -100°F (-73°C).

Low-maintenance, high-durability vertical-axis turbines from Finland's Oy Windside are also presently used successfully at Finland's Antarctic research station. The largest Windside presently available is rated at 22 kW, which is small for such applications, but demonstrates that as part of further analysis, more research on available technologies should be conducted (Windside).

A Mantis 6610 crane manufactured by Spandek is available at the South Pole Station that can be used to install wind turbines. It is rated at 33 tons (29.9 metric tons) and, with the jib installed, it has a max boom of 110 feet (33.5 meters).

Wind Data

Wind data for 2003 were used for the analysis of wind potential at the South Pole Station. In this initial analysis, hourly wind speed values taken at the South Pole Metrological Station were used, although no specific information is available regarding the exact placement and height of this measurement. Figure 6 shows the time series used for the analysis. A histogram of the data indicates that the wind was below 5 m/s only 23% of the time for 2003 and had an average value of 5.3 m/s, in the range expected from historical data.

Load Data

The time-series data used for this analysis are based on plant output from October 2001 to October 2002, which represents the use of the old facility. The data do not show a strong diurnal or seasonal variation, which is similar to other summary data for the site. Little information is available on the energy consumption of the new facility currently being constructed, other than the range provided in the earlier section of this report. To allow analysis of the new facility, the load time series from the old station was scaled to represent the expected loads for the new station. The yearly load profile used in the analysis is shown in Figure 7.

Temperature Data

Temperature data from the South Pole for 2003 show the characteristic, highly seasonal, low temperatures (Figure 8). The lowest hourly temperature recorded for 2003 was negative 73°C.

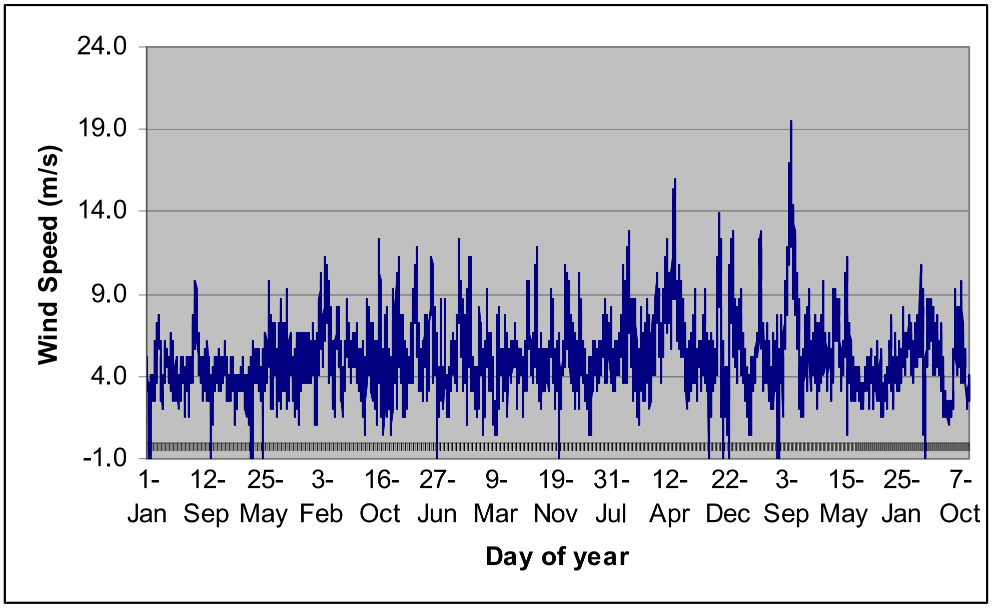

Figure 6: Wind speed measurements taken at the South Pole metrological station for 2003

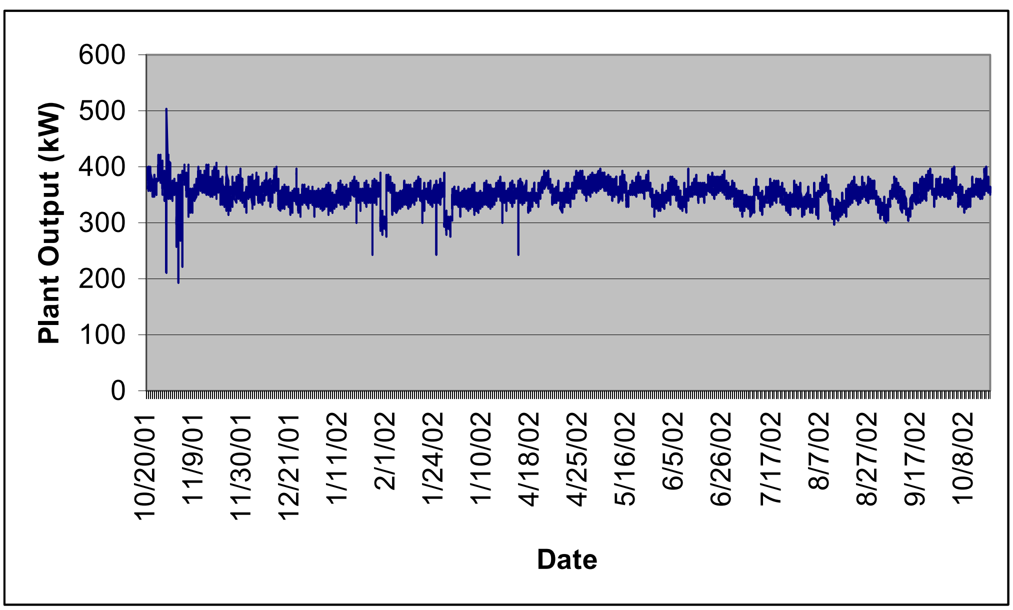

Figure 7: Energy output of the new South Pole Station diesel plant from October 1, 2001 to October 6, 2002

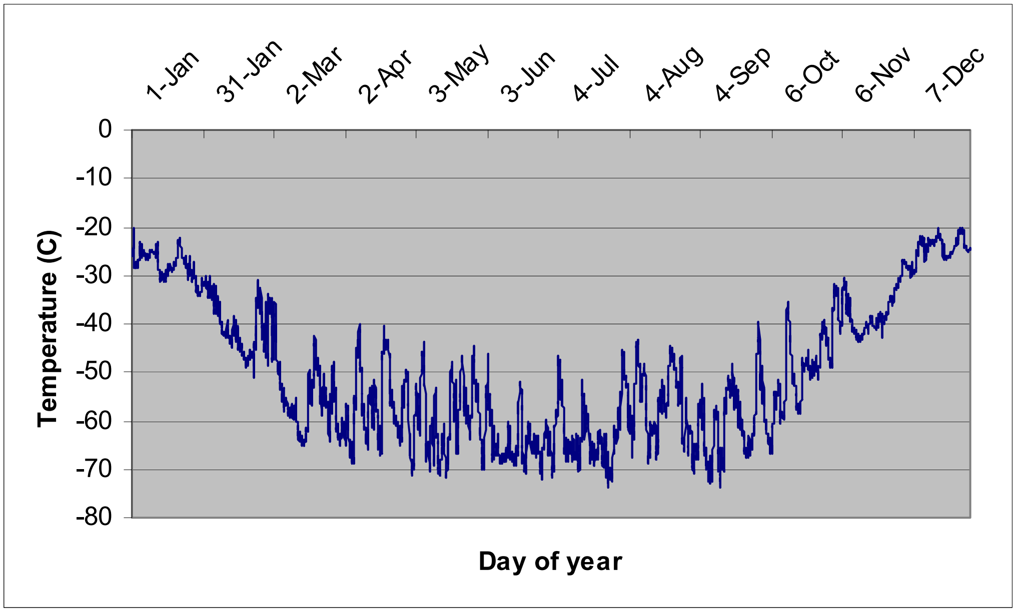

Figure 8: Temperature measurements taken at the South Pole metrological station for 2003

Diesel Plant

The report produced by John Rand stated that the new diesel plant would consist of three Caterpillar 3512 generators (750 kW) and one Caterpillar 3412 diesel generator (250 kW). In conducting research for the plant, it was determined that the Cat 3512 is usually matched with a 1135-kW generator and the 3412 with a 725-kW generator. In this analysis, the fuel curves for the Cat 3412C and 3512B were used, assuming a maximum rated power as provided by the Rand report: 250 and 750 kW, respectively. This results in much higher annual fuel consumption (1,978,231 liters/year) compared to the amount predicted in the Rand report (1,298,800 liters/year). This should be clarified in further analysis.

Costs associated with reducing the need for fuel storage at the South Pole have not been included in this analysis but should be assessed in any further investigation.

Results of South Pole Station Options Analysis

Because any wind energy project at the South Pole will start small, the analysis of this option is quite simple. The Hybrid2 software was used to determine the power performance and economic cost of installing an increasing number of wind turbines. Performance is based primarily on the known wind speed, load, and performance of the wind turbine and diesel plant.

As stated previously, there is a large discrepancy in the expected fuel consumption between the estimations in John Rand's report and those achieved in modeling the system. This difference should be clarified because it will clearly impact the overall cost effectiveness of installing wind power. Based on the load, the expected diesel fuel consumption for the new South Pole station is estimated to be 341,000 gallons/year (1,298,800 liters/year)

As a result of the relatively low wind speeds assumed at the site, the impact of installing wind turbines is limited, but it is still quite cost advantageous. Figure 9 displays the results of simulating between one and 10 100-kW wind turbines at the South Pole. Additional results are included in Table 5. The upper limit of 10 wind turbines was used because of the issues of penetration and simply the sheer number of wind turbines. This system would constitute a low- to medium-penetration power system (see appendix); thus few additional systems controls would be required. The installation of nine 100-kW wind turbines at the site would provide about 50% of the station's annual power demand in addition to 960 MWh of energy that could be used for heating or other direct-process applications. The use of nine turbines would reduce fuel consumption by almost 23% (440,783 liters/year). The investigation of a power system using more wind, although likely to be economic, would require the installation of many more wind turbines with diminishing returns for the installation of each additional turbine. However, the installation of more wind turbines could reduce diesel fuel consumption significantly and should be investigated once more experience has been gained in using wind power at the Pole. The total capital cost of installing nine turbines would be approximately $4.3 million.

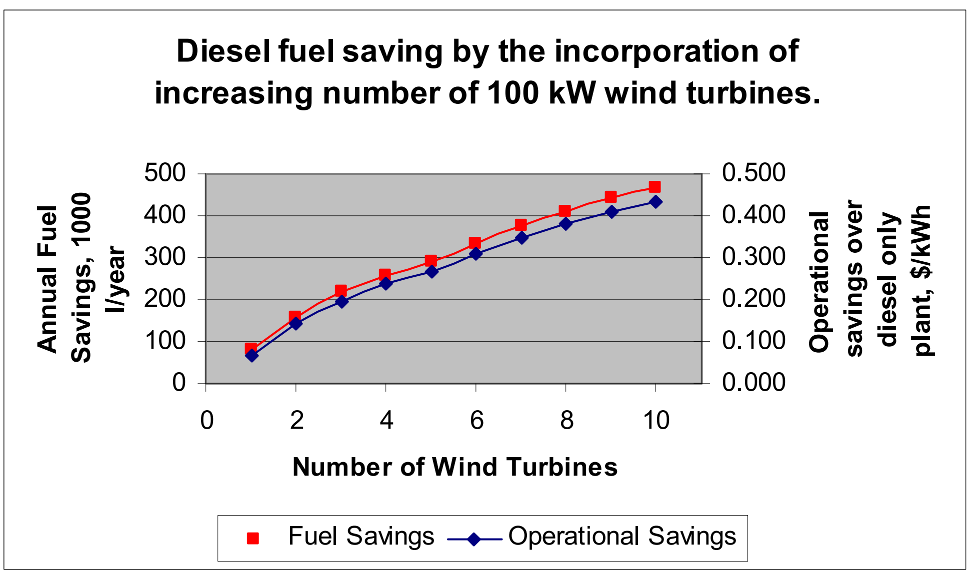

Figure 9: Results of the wind energy use analysis at the South Pole Station

Table 5: Economic Impact of Using Wind Energy at South Pole Station

Input		Performance Results			Economic Results		
Turbine		Fuel Savings	Energy from Wind	Extra Energy*	Savings	Simple Payback	Capital Cost
#		1000 l/year	%	MWh/yr	$/kWh	yr	M$
0		0.0	0.0	0	0	0	0
1		82.0	5.9	1.6	0.055	1.84	0.468
2		159.0	11.7	27.5	0.115	1.77	0.935
3		216.7	17.6	110.2	0.158	1.91	1.403
4		258.5	23.5	240.3	0.187	2.11	1.870
5		290.1	29.4	400.6	0.206	2.34	2.338
6		334.6	35.2	517.6	0.237	2.42	2.805
7		376.4	41.1	645.9	0.386	2.45	3.293
8		411.4	47.0	795.6	0.288	2.61	3.740
9		440.8	52.9	961.2	0.305	2.74	4.208
10		468.1	58.7	1131.1	0.320	2.86	4.675

* Extra energy could be used for heating or melting ice for drinking water

Further Data Needed to Refine the South Pole Station Analysis

The following data should be obtained to refine the analysis conducted as the basis of this report.

Load

- Conduct a detailed energy audit of current and planned buildings
- Updated estimates of the expected load for the new South Pole facility
- Estimate of the total thermal energy loads for the building and auxiliary energy needs, such as melting ice for water.

Diesel Plant

- Clarification of the current diesel configuration, unit specification, and size
- Fuel-use curves of the diesel engines on site
- Updated information on fuel price, usage, and storage availability
- Costs of expected fuel storage expansion.

Wind Data

- Measurement of free-stream airflow at a height of 20m or 30m, upwind of the station in a location where turbine installation would be possible.

Constraints

- Specification of available area for a proposed wind farm in proximity to the South Pole station
- Analysis of potential impact of wind turbines on any ongoing or planned scientific experiments
- Specification of maximum transport and pull force available at the South Pole.

Conclusion

Based on the results of this analysis, there is clear potential to use wind energy to reduce the power generation costs, harmful air emissions, and fuel needs at both stations.

This initial analysis indicates that a large potential savings could be realized by incorporating wind energy into the existing diesel plants at the South Pole Station. The economic impact of using wind power at McMurdo is not as extreme, but it is cost effective and would significantly reduce diesel fuel consumption. Given the amount of wind energy that could be included in the systems at McMurdo and South Pole Station, the current diesel plants will continue to operate, at least initially, as they currently are. Any savings will result from a reduction in fuel consumption and subsequent reduced fuel storage requirements.

Both of these analyses are based on data that are generally out of date or limited in nature; thus the results should be considered preliminary. However, even with the limitations of the data used in the analysis, the increasing electric demand (which leads to increased fuel storage and transportation needs) and the growing cost of diesel fuel will only make wind more financially attractive in any further analysis. The study did not assess the impact of reduced heat availability from the diesel plants or the economic impact of reducing the size of diesel fuel storage expansion.

To advance the assessment of these opportunities, several steps should be taken at the McMurdo and South Pole stations. These include obtaining better load and power system data following a detailed energy audit of each station; more advanced wind measurement at McMurdo and initiating a wind site-specific measurement program at South Pole. Additionally, further analysis is required to quantify the impact of reducing the available ‘waste’ heat from the generators due to the reduction of diesel generator electrical output.

If it were determined that this opportunity was to be pursued, the next step would be to collect the data called for in this report and then conduct a more detailed assessment of potential options, turbines, and systems specifications.

References

As mentioned in the introduction, information used in the report was largely obtained from unpublished reports: John Rand's Considerations of Renewable Energy Resources for the South Pole and several field reports filed by Ed Cannon following survey trips to McMurdo and the South Pole. The following references have also been cited in the text.

Baring-Gould, E. I. (1996). Hybrid2: The Hybrid System Simulation Model Version 1.0 User Manual. 62 pp.; NREL Report No. TP-440-21272.

ENERCON GmbH, E-30 Product Brochure, www.wind.enron.com/index.html

Entegrity Wind Systems Inc, EW15 product brochure, www.entegritywind.com

Fuhrlander Wind Turbines, FL250 product brochure, www.lorax-energy.com

Northern Power Systems, NorthWind NW100/19 product brochure, www.northernpower.com/

Oy Windside, www.windside.com/

Vergnet WE Development, GEV 26/220 product brochure, www.vergnet.fr

Appendix A: Primer on Diesel Retrofit Opportunities

The following background information provides an overview of the technology options available to retrofit a diesel power system. This is not meant to be all-inclusive and only covers internal changes to the power station. This does not address external efficiency measures that may also improve the performance of the power station.

The amount of wind at McMurdo and the South Pole Station discussed in this report is limited. It may be possible to install more wind at the South Pole, but this was not considered at this time.

There is a ranking of options for retooling a diesel power station, ranging from simply ensuring that the diesels installed at the plant are appropriately sized for the expected loads through the implementation of advanced renewable-based power systems (Baring-Gould 1997).

Resize Diesel Generators

The first opportunity to reduce the fuel consumption of a diesel power plant is to consider the size of engines that make up the plant. In many cases, diesel engines are oversized for the expected load because they are usually sized for the maximum possible load, not the normal or early morning load. Although this may seem like a safe procedure that lowers the risk of improper sizing, it may increase the fuel consumption of the plant. The impact of this will depend greatly on the size and age of the diesels under consideration because newer diesel engines have much better low-power efficiency.

Apply Advanced Diesel Control

Larger diesel plants often contain multiple diesel engines of various sizes. In these systems, it is more likely that the diesels will be the appropriate size; however, the diesels operating at any given point may not be the most efficient combination to cover that load. In these systems, controls can be placed on the diesel generators to enable automated dispatch and more efficient operation. Each genset is provided with controls for auto starting, synchronization, and load matching while a master control is used to coordinate diesel dispatching and load sharing. Automated systems have the additional advantage of detailed operational data collection and monitoring. Fuel savings depend on the current system design and dispatch strategy but tend to be cost effective in larger systems in which the current dispatch strategy is either inefficient or labor intensive. The use of advanced controls may add a level of technical sophistication that will only be appropriate in larger communities.

Install Batteries and a Power Converter to Cover Low-Load Periods

This approach is applicable in a single-diesel system if the community experiences periods of very light loading compared to the peak load. In these cases, the existing diesel is generally oversized for the low load period; thus it operates with poor efficiency. A retrofit battery bank and power converter, in which stored energy from the battery is used to power the converter and cover the load, allows the generator to be turned off during periods of light loading. The batteries are then recharged when the generator is operating at higher efficiency. This approach may also be used to expand the hours of service of a particular plant without greatly increasing the system operation costs. In multiple-diesel systems, the addition of batteries can preclude the need to start an additional generator that must run at low loading to cover power fluctuations over the rating of the primary generator. In either case, the generator recharges the batteries during other periods of the day. The decision of whether to install a converter/battery bank or a smaller diesel to cover these low-load periods is dependent on the ratio of low load to diesel size and should be considered carefully. The potential cost savings depend on the load profile and the sizes of the diesel generators. The size of the battery bank depends on the energy requirements of the low-load period. The size of the inverter depends on the magnitude of the load during the low-load period. Both the initial cost and the periodic replacement cost of the batteries must be weighed against the reduction in operation and maintenance expenses. In this system, the batteries cover the load in the early morning and then are recharged by the diesel later.

Install Renewable Technology to Reduce Diesel Operation

Retrofitting diesel power plants to incorporate renewable-based power generation allows for a potentially less expensive generation source to be used. In plants with many large diesels, where there is always a demand for power, the renewable-based energy is used to offset power production by the generators, potentially to the point at which all generators can be shut off. The addition of renewable-based power may also reduce the number of generators operating at any given time, thus reducing the diesel maintenance requirements. Because system dynamics and power stability are of primary concern, the power system must be designed to ensure that the inclusion of the renewable-based generation does not degrade overall power quality.

This approach can be very cost effective but is capital intensive because of the cost of the new generation and system controls. The potential cost savings depend on the renewable resource, component maintenance costs, equipment capital costs, and the fuel price. Based on current prices, photovoltaics (PV) is usually not cost effective in large systems when compared to the marginal cost of diesel fuel. Plants with access to reasonable wind resources, generally greater than Class 1 (5.9 m/s annual average), could significantly reduce operating costs by the inclusion of some amount of wind generation (Allderdice and Rogers 2000; Baring-Gould et. al. 2000, 2001; Jimenez and Lawand 2000; Jimenez and Olson 1998).

The next sections describe considerations and configurations of wind/diesel power stations.

Wind/Diesel Applications

Wind/diesel power systems can vary from simple designs in which wind turbines are connected directly to the diesel grid with a minimum of additional features to more complex systems. Two overlapping concepts depict the system design and required components: the amount of energy that is expected from the renewable sources (system penetration) and the decision to use a storage device to remedy system energy fluctuations. Given today's technology, these issues are usually selected by the system designers as a starting point for system design (Ackermann et. al. 2005; Baring-Gould et. al. 2003; Hunter and Elliot 1994). These concepts are described in the following section.

Renewable Penetration

When incorporating renewable-based technologies into large power systems, the amount of energy that will be obtained from the renewable sources must be determined because this will dictate which components will be used. Steve Drouilhet developed the following classification and definitions of system penetration that characterize the levels of system complexity:

$$\text{Instantaneous Penetration} = \frac{\text{Wind Power Output (kW)}}{\text{Primary Electrical Load (kW)}}$$

and

$$\text{Average Penetration} = \frac{\text{Wind Turbine Energy Output (kWh)}}{\text{Primary Electrical Load (kWh)}}$$

The difference in these equations is the units. Instantaneous penetration is in terms of power; thus, it is the ratio of how much power is being produced by the renewable resources at any specific instant. The average penetration is in terms of energy; it includes a time domain and is thus measured over days, months, or even years. In some sense, average penetration is in the domain of the economist and instantaneous penetration falls in the realm of the engineer. Drouilhet also proposed a three-level classification system based on system penetration that separates systems along power and system control needs (Table A.1). There are no references that can be attributed to Steve Drouilhet on this topic; however, the methodologies are discussed further in Ackermann 2005 and Baring-Gould et. al. 2003.

Table A.1: Penetration Class of Wind-Diesel Systems (Proposed by Steve Drouilhet)

<table>
<tr><th rowspan="2">PENETRATION CLASS</th><th rowspan="2">OPERATING CHARACTERISTICS</th><th colspan="2">PENETRATION</th></tr>
<tr><th>PEAK INSTANTANEOUS</th><th>ANNUAL AVERAGE</th></tr>
<tr><td>LOW</td><td>▪ Diesel runs full-time
▪ Wind power reduces net load on diesel
▪ All wind energy goes to primary load
▪ No supervisory control system</td><td>< 50%</td><td>< 20%</td></tr>
<tr><td>MEDIUM</td><td>▪ Diesel runs full-time
▪ At high wind power levels, secondary loads dispatched to ensure sufficient diesel loading or wind generation is curtailed
▪ Requires relatively simple control system</td><td>50% – 100%</td><td>20% – 50%</td></tr>
<tr><td>HIGH</td><td>▪ Diesels may be shut down during high wind availability
▪ Auxiliary components required to regulate voltage and frequency
▪ Requires sophisticated control system</td><td>100% – 400%</td><td>50% – 150%</td></tr>
</table>

Wind/Diesel Power System Configurations

Low-Penetration Systems: Many low-penetration systems have been installed worldwide. These vary from small to relatively large isolated grids, such as those found on several Greek islands. In fact, some large grids, such as those found in certain areas of the United States and Europe, reach a wind power penetration that would classify them in the same category as low-penetration systems. Basically, low-penetration systems are those in which the renewable generation source is just another source, requiring no special arrangements. The control technology required at this level of generation is trivial, especially given the control, flexibility, and speed of modern diesel and wind systems. In many systems, no form of automated control is required—the wind turbines act under their commercial controllers and an operator monitors all system functions. Because the diesel engines are designed to allow for rapid fluctuations in power requirements from the load, the addition of wind has very limited impact, if any, on the ability of the diesel control to provide the remaining difference. Issues of spinning reserve, a term used to represent the availability of instantaneous system capacity to cover rapid changes in system load or energy production, are addressed by the allowable capacity of the diesel engines, which in many cases can run at 125% rated power for short periods of time with no adverse impact on the diesel or generator. A generic schematic of a low-penetration system is shown in Figure A.1 (Lundsager and Madsen 1995 and Lundsager et. al. 2001).

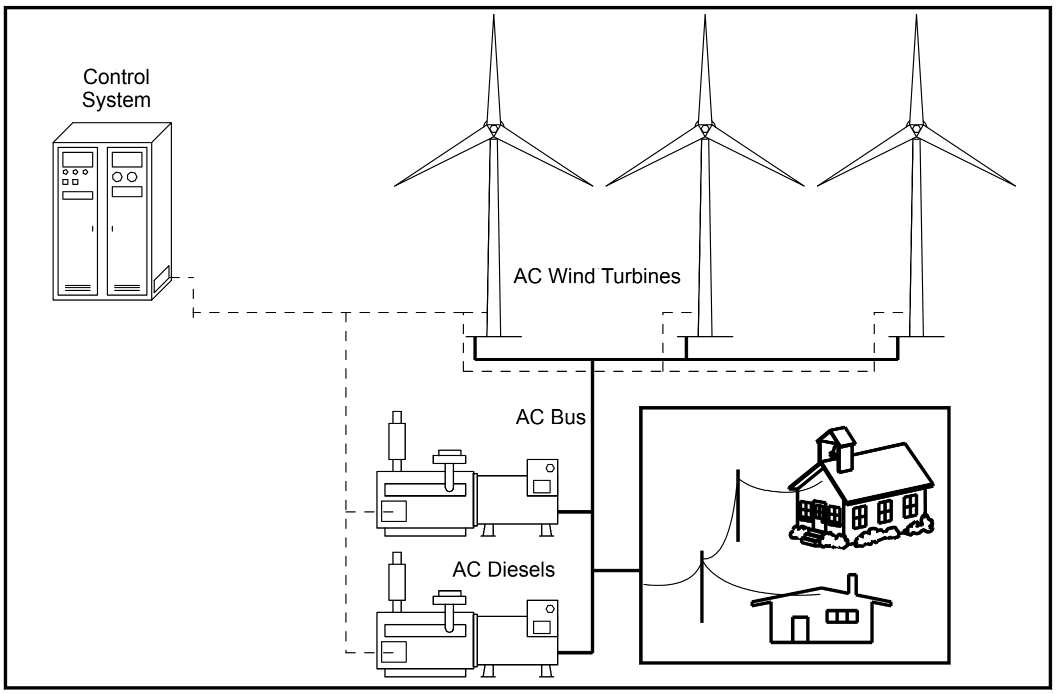

Figure A.1: Schematic of low-penetration wind/diesel hybrid

Medium-Penetration Systems: Systems with larger ratios of renewable energy contribution fall into this category. Allowing power penetrations of up to 50% will allow any under-loaded diesel generators in multiple diesel plants to be shut off or to be switched to a smaller unit for production. This, in turn, will reduce plant diesel consumption and reduce diesel engine operation. However, this may also open the power system to potential shortfalls, assuming the loss of one or more of the wind generators or diesel engines. In addition, with a large penetration of energy being produced by the variable renewable source, it will become harder for the operating diesel units to tightly regulate system voltage and maintain an adequate power balance. There are options to ensure that the high-power-quality requirements of the power system are maintained, even with half of the energy provided by renewable sources. Some of the options include power reduction capabilities within the wind turbine controller, the inclusion of a secondary load to ensure that no more than a specified amount of energy will be generated by the wind, installation of capacitor banks to correct power factor, or even the use of advanced power electronics to allow real-time power specification.

Spinning reserve on medium-penetration power systems requires experience in regard to proper power levels and system commitments but is not considered technically complex. Such spinning reserve questions should be handled on a case-by-case basis but can be partially solved by using options, including the use of advanced diesel controls, the installation of a modern diesel engine with fast start and low-loading capabilities, controlled load shedding or reduction, power forecasting, and proper system oversight. Combined with the use of variable-speed or advanced-power conditioning available on many modern wind turbines, the control requirements of medium-penetration systems are quite simple. The ability to provide high power quality in medium-penetration power systems has been demonstrated for years in a number of highly important locations. The most notable examples are the military diesel plants on San Clemente Island and Ascension Island and the power system in Kotzebue, Alaska. All of these systems have experienced power penetration at or above these guidelines set for medium-penetration systems (McKenna and Olsen 1999).

High-Penetration Systems: Although this technology has been demonstrated on a commercial basis, high-penetration wind-diesel power stations require a much higher level of system integration, technology complexity, and advanced control. The principle of operation of high-penetration systems is that the required equipment is installed in addition to the wind turbine so that the diesel can be shut off completely when there is an abundance of renewable-power production. Any instantaneous power production over the required electrical load, an instantaneous penetration over 100%, is supplied to a variety of controllable secondary loads. In these systems, synchronous condensers, load banks, dispatchable loads (and possibly storage in the form of batteries or flywheel systems), power converters, and advanced system controls are used to ensure power quality and system integrity. Spinning reserve is created through the use of short-term storage or the maintenance of a consistent oversupply of renewable energy. Although these systems are demonstrated commercially, they are not yet considered a mature technology and have not been demonstrated on systems larger than approximately 200-kW average load. A generic schematic of a high penetration with storage is shown in Figure A.2 (Drouilhet 2001).

Systems Storage: Until recently, it was assumed that wind-diesel systems without storage were theoretical, possibly born out of short-term testing in test-stand-based power systems. This is no longer the case. Commercially operating short-term and no storage systems have been installed in recent years, demonstrating that both technology choices are viable.

In systems incorporating storage, the storage is used to cover short-term fluctuations in renewable power. The premise of this system design is that a large penetration of renewables is used (up to 300% of the average power requirements). When the renewable-based generators supply more power than is needed by the load, the engine generators can be shut down. During lulls in the renewable power generation, discharging the battery bank or other storage device supplies any needed power. If the lulls are prolonged or the storage becomes discharged, an engine generator is started and takes over supplying the load. Studies have indicated that most lulls in power from the wind are of limited duration, and using storage to cover these short time periods can lead to significant reductions in the consumption of fuel, generator operational hours, and reduced generator starts.

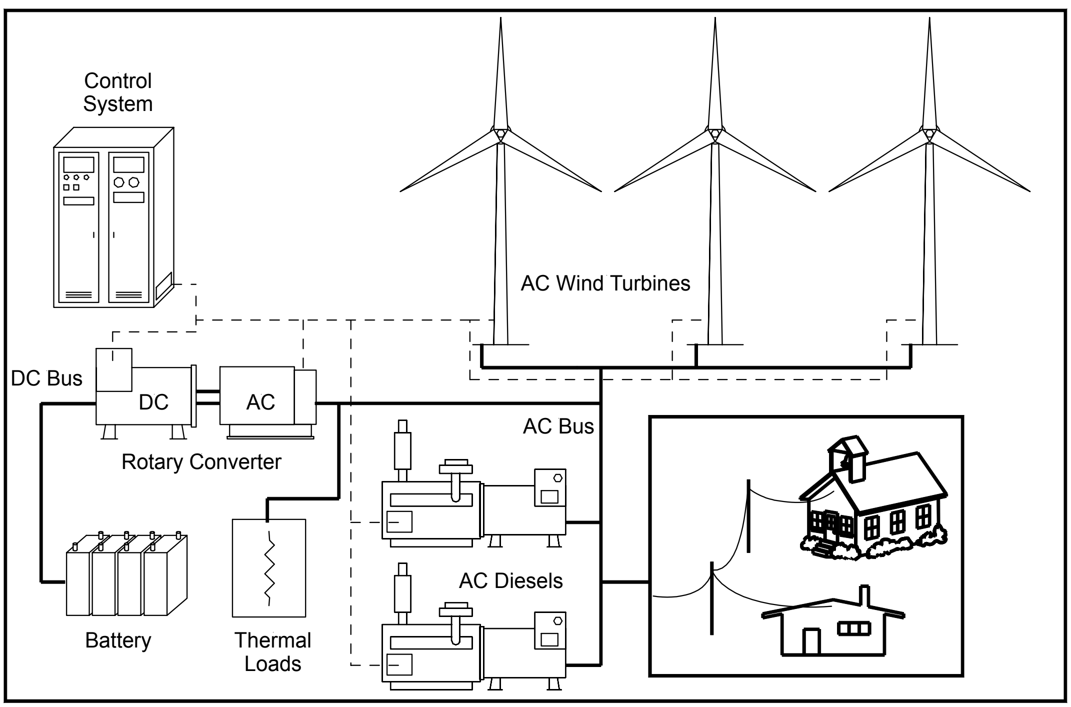

Figure A.2: Schematic of high-penetration wind/diesel power system using a rotary power converter

In large power systems, the installation of a battery bank to cover shortfalls in renewable production may not be feasible, mainly because of cost. However, without storage it is very difficult to control the stability of a conventional power grid with large quantities of renewable power—thus the challenge of hybrid systems without storage. This configuration is based on the AC bus and does not use batteries to provide grid stabilization. The basic premise of these systems is that the installed capacity of the renewable technology is much larger than the load. When the renewable devices are operating and producing more energy than is needed by the load by some margin, usually between 125% and 150%, the dispatchable generators can be turned off. External control devices, such as dispatchable secondary loads, fast-acting dump loads, synchronous condensers, and advanced diesel control are used to maintain system stability and control. If the renewable energy dips below a specified threshold, a generator is started to ensure power security or some of the dispensable loads can be disconnected to increase the systems headroom. This type of system produces a large amount of extra energy that must be used if the project is to be economical. This is completed with a large thermal storage tank that acts as a buffer for the electrical load, allowing the smoothing of the variable wind energy and dispatching a diesel generator when there is not enough energy to cover the loads or if the thermal storage tank temperature drops below a specified limit. The control system and hardware requirements are less complex than a system using battery storage; however, the facility must have a large and expensive heating requirement to cover the cost of the additional infrastructure, which is the case for Antarctica.

All high-penetration systems, with and without storage, have been installed in northern climates where the extra energy can be used for heating buildings or water, displacing other fuels. In these systems, it may be wise to install uninterruptible power supplies (UPSs) on critical loads. Although only a limited number of systems have been installed, the concept is economically attractive and can drastically reduce fuel consumption in remote communities (Beyer et. al. 1987; Shirazi and Drouilhet 1997).

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14. ABSTRACT *(Maximum 200 Words)*
This report summarizes an analysis of the inclusion of wind-driven power generation technology into the existing diesel power plants at two U.S. Antarctic research stations, McMurdo and Amundsen-Scott South Pole Station. Staff at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) conducted the analysis. Raytheon Polar Services, which currently holds the private sector support contract for the two research stations, was a major contributor to this report. To conduct the analysis, available data were obtained on the wind resources, power plant conditions, load, and component cost. Whenever possible, we validated the information. We then used NREL's Hybrid2 power system modeling software to analyze the potential and cost of using wind turbine generators at the two aforementioned facilities. Unfortunately, the power systems and energy allocations at McMurdo and South Pole Station are being redeveloped, so it is not possible to validate future fuel use. This report is an initial assessment of the potential use of wind energy and should be followed by further, more detailed analysis if this option is to be considered further.

15. SUBJECT TERMS
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